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Miami Univ., Coral Gables

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CHARACTERIZATION OF METHANOL/GASOLINE BLENDS AS AUTOMOTIVE FUEL - PERFORMANCE AND EMISSIONS CHARACTERISTICS

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Recent concern about environmental problems and the eventual shortage of conventional petroleum-based fuels coupled with the potential of obtaining methyl alcohol (methanol) as a product of coal gasification has brought about a recent interest in the use of methanol as a fuel. In order to assess the feasibility of using methanol as a motor vehicle fuel, either alone (neat) or as a blend in gasoline-type base stocks, its performance, emissions and practical use characteristics must be ascertained. To this end the authors and their colleagues are conducting a series of experiments which will determine methanol blend-fueled engine characteristics information. This report contains some of the results obtained to date. (Portions of this document are not fully legible).

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TABLE OF CONTENTS

Page No.

I. INTRODUCTION 1

II. PRESENT INVESTIGATION 2

A. OBJECTIVES 2

B. FUELS 3

C. ENGINE 4

D. MEASUREMENTS 4

D-1 Measuring Methods 4

D-2 Experimental Uncertainty 4

E. TEST PROCEDURES 5

E-1 Calibration Check at "Standard" Conditions 5

E-2 Type O Tests 6

E-3 Type I Tests 6

E-4 Type II Tests 6

F. METHODS EMPLOYED FOR TYPE O TEST DATA ANALYSIS 7

F-1 Objective 7

F-2 Data Presentation Format 8

F-3 Statistical Analysis - Description of Methods Used 8

F-4 Statistical Analysis - Presentation and Interpretation of Results 12

F-5 Discussion 14

TABLE OF CONTENTS (cont.)

Page No.

III. EXPERIMENTAL RESULTS 16

A. TYPE O TESTS 16

- A-1 Fuel-Air Equivalence Ratio 16
- A-2 MBT Spark Advance 19
- A-3 Torque 20
- A-4 Brake Thermal Efficiency 21
- A-5 Volumetric Efficiency 22
- A-6 Carbon Monoxide Mass Emissions 23
- A-7 Nitric Oxide Mass Emissions 23
- A-8 FID Total Hydrocarbon Mass Emissions . . . 24
- A-9 Carbon Dioxide Mass Emissions 25
- A-10 Oxygen Mass Emissions 25
- A-11 Geometric Distribution 25

B. TYPE I TESTS 27

- B-1 Fuel-Air Equivalence Ratio 27
- B-2 Torque, Engine Speed 27
- B-3 Brake Thermal Efficiency 27
- B-4 Carbon Monoxide Emissions 28
- B-5 Nitric Oxide Emissions 28
- B-6 FID Total Hydrocarbon Mass Emissions . . . 28

TABLE OF CONTENTS (cont.)

Page No.

C. TYPE II TESTS 28

C-1 Manifold Vacuum 29

C-2 Blend Leaning Effect 29

C-3 Brake Thermal Efficiency 29

C-4 Oxygen Emissions 30

C-5 Carbon Monoxide Emissions 30

C-6 Nitric Oxide Emissions 32

C-7 FID Total HC Emissions 32

IV. SUMMARY AND CONCLUSIONS 33

V. ACKNOWLEDGMENTS 37

VI. REFERENCES 38

LIST OF TABLES 39

TEXT OF TABLES 40

LIST OF FIGURES 86

TEXT OF FIGURES 92

APPENDIX A - ANALYSIS OF EXHAUST GAS 166

APPENDIX B - PERFORMANCE AND EMISSIONS CHARACTERISTICS PROGRAM 171

APPENDIX C - LIST OF STANDARD CONDITIONS TEST RESULTS FIGURES 184

I. INTRODUCTION

Alcohol has been promoted as a motor fuel for almost 70 years. Most of the early work was concerned with the use of ethyl alcohol (ethanol), which could be produced by fermentation of grain and other farm products as well as synthetically. The impetus behind these studies was the desire to develop new outlets for farm produce and to develop energy sources other than those based on petroleum. Excess cost and the absence of technical advantages to justify a higher cost prevented the general use of ethanol as a motor fuel (1)*.

Recent concern about environmental problems and the eventual shortage of conventional petroleum-based fuels coupled with the potential of obtaining methyl alcohol (methanol) as a product of coal gasification (2) has brought about a recent interest in the use of methanol as a fuel.

In order to assess the feasibility of using methanol as a motor vehicle fuel, either alone (neat) or as a blend in gasoline-type base stocks, its performance, emissions and practical use characteristics must be ascertained. To this end the authors and their colleagues are conducting a series of experiments which will determine methanol blend-fueled engine characteristics information found to be lacking during their preparation of Reference 3. This report contains some of the results obtained to date. Other results have been presented in Reference 4.

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* Numbers in parentheses designate References in Section VI.

II. PRESENT INVESTIGATION

II. A OBJECTIVES

The present study was concerned with two basic areas of investigation. The first was the determination of the effects on the performance and emissions characteristics of a multicylinder, carbureted engine operating at MBT spark advance, resulting solely from a change in fuel from a base stock representative of unleaded gasoline to blends of the base stock and methanol. To achieve this first objective the engine was operated at constant speed and manifold vacuum over a range of fuel-air equivalence ratios. The fuel's effects on performance and emissions characteristics were then ascertained by comparing the various performance and emissions characteristics determined while using methanol blends as a fuel with those characteristics determined at the same fuel-air equivalence ratio while using the base stock as a fuel. The first area of study is felt to be of fundamental importance and an aid to understanding the results obtained during the second area of study.

The main purpose of the second area of study was to estimate what would happen to its performance and emissions characteristics if the above-described engine were to power an automobile traveling at constant speed while being fueled by various blends of methanol and gasoline. To achieve the goals in the second area of the study the engine was fitted with a carburetor whose fuel metering characteristics approximated those of a stock 1974 carburetor. In addition the spark advance was adjusted to the best as could be determined, stock spark advance corresponding to the engine speed and manifold vacuum. The speed of the vehicle being simulated during the tests determined the engine speed and torque requirement.

A third area was investigated during the study which involved determining the changes in performance and emissions characteristics when methanol blends were substituted for gasoline while making no change to any of the controllable engine variables. This third area does not comprise a basic objective, but since the information was readily obtained during testing it is included for completeness.

In summary, the basic objectives of the present investigation were:

1. Determination of the effect of methanol addition to gasoline per se on the various performance and emissions characteristics of a carbureted engine when it is operated at the same as gasoline-fueled operation engine speed, manifold vacuum (unequal torque as the data showed) and equivalence ratio with MBT spark advance.

2. Determination of the effect of methanol addition to gasoline on the various performance and emissions characteristics of a carbureted engine when it is operated at the same as gasoline-fueled operation engine speed and torque (unequal manifold vacuum) with no alteration to the controllable engine parameters other than the throttle setting and with the fuel-air equivalence ratio being determined by a stock carburetor and the spark advance adjusted to the stock value corresponding to the engine speed and manifold vacuum.

In the following sections the fuels, engine, measuring techniques, test procedures, and statistical methods of data analysis employed to attain the objectives are described.

II. B FUELS

Indolene H.O. Clear Motor Fuel III was used as the base stock representative of unleaded gasoline. Mixtures of Indolene and commercial grade methanol were used to represent methanol-gasoline blends. Blend levels of up to 30 volume percent of methanol in Indolene were tested. An X volume percent blend was formed by taking X volume units of methanol and combining them with (100-X) volume units of Indolene. In this report Indolene is also referred to as

0%M and X volume percent blend as X%M.

II. C ENGINE

The four cylinder engine used in this study was manufactured by the Pontiac Motor Division of General Motors Corporation and is described in Reference 5. In order to simulate a modern engine, it was fitted with a 1974 400 cu. in. Pontiac engine cylinder head and cam. The compression ratio was 8.1 to 1.

A modified intake manifold which accommodates a four-barrel Rochester Quadrajet carburetor was used. The carburetor, in turn, was modified to operate on only one of the two primary and secondary circuits. For some of the tests it was necessary to manually control the fuel-air ratio. For these tests an adjustable main metering jet was installed.

The spark advance was manually adjustable with the centrifugal and vacuum advance mechanisms inoperable.

Coolant water inlet and exit temperatures were thermostatically controlled. The radiator and fan were replaced by a cooling tower using fresh city water to maintain the coolant inlet temperature.

II. D MEASUREMENTS

II. D-1 MEASURING METHODS

Table 1 summarizes the various measurements that were made during testing. Included are the methods used to make the measurements along with an estimate of the precision (6) of the instruments. These estimates were determined either from manufacturers' specifications and/or calibrations performed during the investigation. In the next section the methods used to estimate the experimental uncertainty of the various measurements are given.

II. D-2 EXPERIMENTAL UNCERTAINTY

In order to determine the experimental uncertainty of the various measurements and the reproducibility of the data, the engine was operated prior to and periodically during the course of each day's testing at a set of "standard" conditions specified in Table 2.

Figures C 1 through C 11, Appendix C, illustrate the values of the measured parameters measured during the "standard" conditions tests. The horizontal axis test numbers refer to the Test Number Values assigned to test points as given in Table 3* which also contains the values of the various measured and derived parameters for all test points. Included in the Appendix figures is the mean value (arithmetic average) and the "standard" deviation of the various measurements at the "standard" condition operating point.

In a similar way, Figures C 12 through C 19 illustrate the values of the derived parameters for the "standard" conditions tests. The mean and the "standard" deviation at the "standard" conditions for the derived parameters are also shown in each figure.

II. E TEST PROCEDURES

All testing was carried out under steady state conditions with the engine connected to a water brake dynamometer. Three types of tests were carried out: Type 0, Type I and Type II. The three types are described below along with the "standard" conditions check point mode of operation which was used for calibration purposes.

II. E-1 CALIBRATION CHECK AT "STANDARD" CONDITIONS

After performing necessary daily instrument calibrations the engine was adjusted to the "standard" conditions described in Table 2. This was done to detect engine and instrumentation malfunction. The engine was also operated this way periodically during a day's testing. For comparison purposes the measured horse power, and brake mean effective pressure were corrected to standard conditions (12).

* Table 3 is the computer output which contains the test results used in this report.

II. E-2 TYPE O TESTS

In order to determine the effect resulting solely from the addition of methanol to gasoline, that is, objective 1 of Section II. A, the Type O Tests were conducted. During these tests the throttle position, and dynamometer load control were adjusted to maintain a constant engine speed (2000 RPM) and manifold vacuum [16 in. Hg (54 kPa)] while the equivalence ratio was varied over similar ranges for the various methanol blends by changing the setting of the carburetor's adjustable main metering jet. In addition, the spark advance was adjusted to the predetermined MBT spark advance value corresponding to the equivalence ratio. Such tests were conducted for 0, 20 and 30% blend levels.

II E-3 TYPE I TESTS

During the Type I tests, the engine was adjusted to a predetermined engine speed and manifold vacuum while using Indolene fuel with the stock main metering jet in the carburetor and the ignition timing adjusted to manufacturers' specifications. Subsequently, methanol blends (10, 20 and 30%) were substituted for the Indolene while making no change in the engine adjustments. The throttle setting and the spark advance were not changed; neither was the dynamometer load control valve.

Since the Type I tests were carried out for only a limited set of operating conditions, namely 2000 RPM engine speed and 16 in. Hg (54 kPa) or 10 in. Hg (34 kPa) manifold vacuum, and since the engine adjustments and corresponding vehicle speed are the same as those in some of the more extensive Type II test series, the details of how the Type I tests operating conditions were selected are described in the next Section.

II. E-4 TYPE II TESTS

The Type II tests were carried out to achieve the second objective given in Section II. A. As in the Type I tests, the engine was adjusted to a predetermined engine speed and torque using Indolene fuel. Subsequently methanol blends

(10, 20 and 30%) were substituted. This substitution resulted in a decrease in engine speed and torque. The procedure was to lower the manifold vacuum by opening the throttle until the Indolene-fueled-operation engine speed and torque were regained. In addition, if necessary, the spark was retarded to correspond to the spark advance that would have been present had the vacuum advance mechanism been operable.

The engine speeds selected were 1150, 1500 and 2000 RPM and corresponded to vehicle speeds of approximately 30, 40 and 52 mph (48, 64 and 84 km/hr).

The torque values selected approximated one-half the torque (same mean effective pressure) requirement of a full-sized American car, cruising at 30, 40 and 52 mph. In addition, at 2000 RPM engine speed (52 mph), tests were carried out at a torque value higher than the 52 mph cruise torque value. The engine speed, torque, and corresponding vehicle speed and Indolene-fueled-operation manifold vacuum values are presented in Section III. B. Also presented are the values of Indolene-fueled-operation spark advance. These values were the best estimates that could be made from available information of spark advance versus engine speed and manifold vacuum for a 1974, 400 cu. in., non California vehicle, Pontiac engine.

The values of spark advance used during the methanol blend-fueled operation Type II tests are given in Table 3.

II. F METHODS EMPLOYED FOR TYPE O TEST DATA ANALYSIS

II. F-1 OBJECTIVE

The objective of the Type O tests was to answer the question: What effect does methanol addition have on the various performance and emissions characteristics when the engine is operated at the same as gasoline-fueled operation engine speed, manifold vacuum, equivalence ratio, and MBT spark advance?

As will be seen in Section III the changes in performance and emissions characteristics determined during the

Type O tests attributed to the methanol addition are small being close in magnitude to the experimental uncertainty. The objective of the data analysis presented in this Section was to assess the statistical significance of the observed changes. The format used for data presentation and the methods of statistical analysis employed are described in this Section.

II. F-2 DATA PRESENTATION FORMAT

For each of the blend levels tested the experimentally determined characteristic of interest was plotted as a function of the fuel-air equivalence ratio Φ_c. See for example Figure 7 where the performance characteristic torque is plotted versus equivalence ratio for Indolene. Also see Figures 8 and 9 which illustrate similar information for the the 20 and 30%M blends respectively. All such Figures are for 2000 RPM, 16 in. Hg manifold vacuum and MBT SA.

II. F-3 STATISTICAL ANALYSIS - DESCRIPTION OF METHODS USED

To estimate the degree of association or co-variation of the various performance and emissions characteristics with methanol blend level,statistical methods of regression analysis and hypothesis testing were employed. The objective of the regression analysis should not be misconstrued. It was not to determine the best functional relationship among the variables. Rather, the objective of the regression analysis as combined with the hypothesis testing was to estimate the degree to which the different variables are associated (7).

The statistical analysis for each performance and emission characteristic was comprised of three parts:

[1] The first part consisted of selecting a regression model or function which correlated the measured characteristic of interest with equivalence ratio for each of the blend levels at constant engine speed, manifold vacuum and MBT SA. No single function was found which would satisfactorily correlate each of the characteristics with

equivalence ratio over the entire range of equivalence ratios tested. For the purpose of the present study it was not necessary to find such a function and over the range of equivalence ratios of practical interest (viz. $0.88 \leq \Phi_c \leq 1.22$) it was found that for each blend level a polynomial function of the form

$$C = a_0 + a_1\Phi_c + a_2\Phi_c^2 + a_3\Phi_c^3 \qquad (1)$$

satisfactorily correlated the data. In Equation (1): C is the characteristic of interest, Φ_c the fuel-air equivalence ratio and the a_i's the parameters of the regression model. The parameters a_i were determined by the method of least squares using the computer program Polynomial Regression as described in Reference (8). The regression curve of C versus Φ_c, as defined by Equation (1), for each of the blend levels was then plotted on the corresponding characteristic versus equivalence ratio data plots. See for example Figures 7, 8 and 9 where the torque regression curves for the 0, 20 and 30%M blends respectively, are plotted. Included in the Figures are the values of the a_i's. The characteristic versus Φ_c regression curves for each of the blends were also put on a single graph to better illustrate the effect of methanol addition. See, for example, Figure 10 where the torque versus equivalence ratio regression curves are presented for the 0, 20 and 30%M blend levels. The changes in the characteristic torque resulting from methanol addition, as illustrated by the shifts of the torque regression curves in Figure 10 are small being close in size to the experimental uncertainty. To determine whether the changes were statistically significant the next two steps were carried out. Before describing them, it should be made clear that the above described regression model, Equation (1), is not necessarily the true relationship between the characteristic of interest and equivalence ratio. Rather it is an approximate relationship which, when combined with the below described parts of the analysis, serves the purpose of allowing for determination of the statistical significance of the observed shifts in the various characteristics resulting from methanol addition.

[2] The second part of the analysis consisted of performing a regression analysis of the pooled 0, 20 and 30%M data using the regression models

$$C = b_0 + b_1\Phi_c + b_2\Phi_c^2 + b_3\Phi_c^3 + b_4M \quad (2)$$

and

$$C = c_0 + c_1\Phi_c + c_2\Phi_c^2 + c_3\Phi_c^3 + c_4M\Phi_c \quad (3)$$

The parameters of the regression models b_i and c_i were determined by the method of least squares using the computer program BMD 03 R described in Reference (9). The reason for selecting two regression models [Equations (2) and (3)] was that the methanol addition appeared to influence some characteristics by the same degree for all equivalence ratios; for other characteristics the degree of methanol's influence appeared to be a function of equivalence ratio. Equation (2) would apply to the former and Equation (3) to the latter situation.

As in part [1] of the analysis the objective here was not to find the regression model which best fitted the data. Rather the objective was to use a model which correlated the data sufficiently well so that statistical inferences could be made regarding the effect of methanol addition on performance or emissions characteristics. The Equations (2) and (3) regression models served the purpose.

[3] The final step in the statistical analysis was to infer whether the inclusion of the M term in Equation (2) or the term $M\Phi_c$ in Equation (3) was statistically significant. If significance was found then methanol was said to have an effect on the performance or emission characteristic of interest.

Two tests were performed to infer statistical significance of the M or $M\Phi_c$ term. The first involved a hypothesis test with the null hypothesis: $b_4 = 0$ (or $c_4 = 0$). The alternate hypothesis was $b_4 \neq 0$ (or $c_4 \neq 0$). The pertinent test statistic was

$$t_{(1-\alpha/2),\ (n-5)} = \frac{b_4 \text{ (or } c_4)}{S_{b_4} \text{ (or } S_{c_4})} \tag{4}$$

which is t-distributed with n-5 degrees of freedom (7). In Equation (4): n is the number of experimental data points (observations); b_4 (or c_4) is the value of the parameter determined by the BMD 03 R computer program (9); S_{b_4} (or S_{c_4}) is the standard deviation or standard error of the regression coefficient b_4 (or c_4) and α is the significance level of the test. The second test for significance of the M or $M\Phi_c$ term was a test for lack of fit (10). For this test the experimental error sum of squares was estimated from both "standard" conditions check point data (Section II. D-2) and data taken at essentially identical values of the independent variables. The pertinent test statistic for the null hypothesis that there is no lack of fit was

$$F_{\alpha',\ \nu_1,\ \nu_2} = \frac{\text{LOF SS} / \nu_1}{\text{EESS} / \nu_2} \tag{5}$$

which is F-distributed with ν_1 and ν_2 degrees of freedom. In Equation (5): ν_1 is the degrees of freedom of the deviation about regression sum of squares minus the degrees of freedom of the experimental error sum of squares, EESS; ν_2 is the degrees of freedom of EESS; LOF SS is the lack of fit sum of squares which is equal to the deviation about regression sum of squares minus the experimental error sum of squares. α' is the significance level of the test.

In addition to inferring the significance of the M or $M\Phi_c$ terms in Equations (2) and (3) the above described hypothesis and lack of fit tests were used to infer the significance of the parameters Φ_c, Φ_c^2, Φ_c^3 in Equations (2) and (3).

II. F-4 STATISTICAL ANALYSIS - PRESENTATION AND INTERPRETATION OF RESULTS.

Pertinent results of the statistical analysis described earlier are presented in tabular form, an example of which is given in Table 4. The interpretation of the Table is given below.

The first entry in the Table is an estimate of the experimental error sum of squares, EESS, of the characteristic. The EESS was found by pooling the sums of squares of the deviation about the mean for subsamples of values of the characteristic. The test points comprising a subsample were for a fixed blend level and the values of the independent variable Φ_c differed from each other by less than one percent. Mathematically the experimental error sum of squares was calculated using Equation (6).

$$\text{EESS} = \sum_{j=1}^{7} \left[\sum_{i=1}^{k} (C_i - \bar{C})^2 \right] \tag{6}$$

In Equation (6) C_i is the measured value of the characteristic C for test point number i. The summation over i is over the k test points of a given blend level making up a subsample, each point within the subsample having values of Φ_c differing from each other by less than 1 percent. $\bar{C}$ is the average value of the C_i's for the k test points. There were seven subsamples, that is seven distinct values of Φ_c ($\pm < 1\%$), as is denoted by the summation over j. There were: three subsamples with 0%M and $\Phi_c = 0.876$, 0.967 and 1.167; three subsamples with 20%M and $\Phi_c = 0.874$, 0.968 and 1.111; one subsample with 30%M and $\Phi_c = 1.086$.

The next entry in Table 4 is the number of test points or observations for all of the blends. In other words n is the number of observations for the pooled 0, 20 and 30% blend data.

For each characteristic up to six functional forms of Equations (2) and (3) were used. The six are listed below:

FUNCTIONAL FORM	FUNCTION	
1	$C_1 = a_{0,1} + a_{1,1}\Phi_c + a_{2,1}\Phi_c^2$	
2	$C_2 = a_{0,2} + a_{1,2}\Phi_c + a_{2,2}\Phi_c^2 + a_{3,2}\Phi_c^3$	
3	$C_3 = a_{0,3} + a_{1,3}\Phi_c + a_{2,3}\Phi_c^2 + a_{4,3}M$	(7)
4	$C_4 = a_{0,4} + a_{1,4}\Phi_c + a_{2,4}\Phi_c^2 + a_{3,4}\Phi_c^3 + a_{4,4}M$	
5	$C_5 = a_{0,5} + a_{1,5}\Phi_c + a_{2,5}\Phi_c^2 + a_{5,5}M\Phi_c$	
6	$C_6 = a_{0,6} + a_{1,6}\Phi_c + a_{2,6}\Phi_c^2 + a_{3,6}\Phi_c^3 + a_{5,6}M\Phi_c$	

For each of these functional forms the computer program BMD 03 R (9) was used to determine the values of the coefficients $a_{i,j}$. In addition the corresponding values of the test statistics

$$t_{i,j} = \frac{a_{i,j}}{S_{i,j}} \tag{8}$$

were determined. Note that the subscripts in Equation (8) do not represent the same things as the subscripts in Equation (4). In Equation (8) $S_{i,j}$ is the standard deviation of the regression coefficient $a_{i,j}$. The $t_{i,j}$ values are presented in the Statistical Significance of Test Results Tables 5 - 9.

If for a given functional form of Equation (7) the value of $t_{i,j}$ is large then the corresponding coefficient $a_{i,j}$ is statistically non-zero and thus the corresponding independent variable (Φ_c, Φ_c^2, Φ_c^3, M or $M\Phi_c$) is significant with regard to correlating the characteristic C with that functional form. If, on the other hand, the $t_{i,j}$ value is small then the corresponding independent variable is not significant and can be deleted from the function. The previous two sentences are quantified by considering the significance levels $\alpha_{i,j}$ which are also presented in the Tables. $\alpha_{i,j}$ is the probability, assuming $a_{i,j}$ to be zero, that a value of $t_{i,j}$ greater than or equal to that given in the Tables could have been obtained by chance.

II. F-5 DISCUSSION

Since the regression model Equations (1), (2) and (3) are not the true relationships between the variables C, Φ_C and M the resulting regression curve (C versus Φ_C) for a given blend level M as obtained from Equation (1) was not the same as the corresponding blend level curve obtained from either Equation (2) or (3). To obtain identical curves the true functional relationships between C, Φ_C and M would have to be exactly of the form given by Equations (1), (2) and (3).

Limiting the extent of the data analysis to the use of these functional form regression models led to the requirement of deciding which model [Equation (1) or Equations (2), (3)] would be used to estimate the change in a particular characteristic C resulting from methanol addition. It was decided to use the regression curves obtained from Equation (1) for this purpose. The reason for making this selection was that each of the Equation (1) curves was generated using the data sample for a single blend level, and it was therefore necessary to estimate the functional relationship between C and only Φ_C. The regression curves thus obtained were found to be good estimates of C versus Φ_C for each blend level. The regression curves (2) and (3), on the other hand, were obtained by pooling the data for all of the blend levels and required the additional estimation of the functional dependence of C on M. The resulting regression curves for the pooled data showed the functional dependence to be not as good an approximation as the assumed functional form of C versus Φ_C for one blend level.

While better functional forms of C versus M could have been found, it was decided that to do so was not necessary because the form chosen served its purpose which was to aid in deciding the statistical significance of methanol addition on the observed change in the characteristic C.

In summary: the shifts in the Equation (1) regression curves (For example Figure 10) were used as estimates of the change in C resulting from methanol addition and the Equations (2), (3) regression analysis was used to determine the statistical significance of the change.

III. EXPERIMENTAL RESULTS

The experimentally determined performance and emissions characteristics corresponding to the test procedures described in Section II. E are described below. Table 3 was generated by the computer program described in Appendix B. In the following Sections, the experimental results contained in this Table are described in detail.

III. A TYPE O TESTS

Sections labeled III. A describe the performance and emissions characteristics measured during steady state operation at 2000 RPM, 16 in. Hg (54 kPa) manifold vacuum and MBT spark advance for 0, 20 and 30%M blends. During these tests the fuel-air equivalence ratio was varied from approximately 20% lean ($\Phi \approx 0.8$) to around 30% rich ($\Phi \approx 1.3$).

III. A-1 FUEL-AIR EQUIVALENCE RATIO

Two values of fuel-air equivalence ratio are presented in Table 3. One of them, given in the seventh row of the Table, is labeled EQ. RATIO FUEL/AIR and was determined by dividing the measured fuel mass flow rate by the measured air mass flow rate and dividing the result by the stoichiometric fuel-air ratio. In the subsequent discussion EQ. RATIO FUEL/AIR will be denoted by Φ_m, where the subscript m denotes that the value was determined from mass flow measurements. The second fuel-air equivalence ratio, given in the twenty-eighth row of the Table, is labeled EQ. R. CHM. and was determined from the measured exhaust constituents and the chemical analysis given in Appendix A. In the subsequent discussion EQ. R. CHM. will be denoted by Φ_c, where the subscript c denotes that the value was determined from the chemical analysis and emissions measurements.

In Figures 1, 2 and 3 the value of Φ_c from Table 3 for each TEST NO. is plotted against the corresponding value of Φ_m. Also included in the Figures is the least squares straight line obtained from the regression model:

$$\Phi_c = d_0 + d_1 \Phi_m \qquad (9)$$

For each blend level, the values, of d_0 and d_1 are given in the Figures. It is observed that Φ_m is greater than Φ_c on the average by about two percent over the range of equivalence ratios tested for all three blend levels.

In Figure 4 the Equation (9) least squares straight lines for the three blend levels are superimposed. The discrepancy, that is difference, between Φ_c and Φ_m is about the same for the three blend levels. There does not appear to be any significant blend level effect. The cause of the discrepancy must therefore be common to all of the blends.

A number of possible causes for the Φ_c versus Φ_m discrepancy can be given. Some of them will only affect the value of Φ_c. Among those causes affecting only Φ_c include errors in: the emission instrument calibrations; the assumed value of the water-gas reaction equilibrium constant K [See Equation (A7); K = 3.8 was used in generating Table 3]; the carbon (X) and hydrogen (Y) content assumed for the Indolene fuel [See Equation (A1); X = 7.0, Y = 13.02 was used in generating Table 3]. Errors in fuel and/or air mass flow rate calibrations would affect Φ_m as would air leaks downstream of the air flow meter.

To determine its effect on Φ_c, the water-gas reaction equilibrium constant K was varied over the range $3.0<K<5.0$. The effect of varying K over this range was found to be negligible.

Varying the assumed value of the hydrocarbon content (Y) of the fuel was also found to not eliminate the Φ_c versus Φ_m discrepancy; changing Y from the Table 3 value of 13.02 to 12.2 resulted in decreasing the difference between Φ_m and Φ_c by only about one-half.

Since the fuel flow meter was carefully calibrated for all of the blends, this source of error was disregarded.

The air flow meter calibration supplied by the manufacturer, on the other hand, was not checked; and, even though care was taken to eliminate it, there could have been some air leakage downstream of the air flow meter. Figure 4 shows the Φ_c versus Φ_m curve obtained assuming an air flow leakage rate plus air flow meter calibration error of 2.4% [that is, an approximately 4 lb/hr (1.81 kg/hr) error in the air flow measurement was assumed]. Such an error is seen to account for a large portion of the discrepancy between Φ_c and Φ_m.

It is of interest to compare the Φ_c versus Φ_m data described above with that of D'Alleva and Lovell (11). Their results were almost identical. They also found Φ_m to be on the average approximately three percent greater than Φ_c. In the light of this finding, it would seem that a contributing factor to the difference between Φ_c and Φ_m could be that the equilibrium analysis used to determine Φ_c does not completely describe the system. To evaluate the factor further work on the exact kinetic condition of the exhaust gas at the sampling location would be necessary, which is beyond the scope of this work. However, the analysis presented in Appendix A is a practical and straightforward means of obtaining Φ_c and is currently widely used.

It was decided that the discrepancy between Φ_c and Φ_m is probably attributable to problems associated with the air flow rate measurement, and that Φ_c is a better approximation of the actual fuel-air equivalence ratio than Φ_m. Thus, Φ_c rather than Φ_m is used in the remainder of this report as the fuel-air equivalence ratio.

It should be pointed out that if the decision of selecting Φ_c rather than Φ_m is a bad one, it does not affect the conclusions made regarding the effect of methanol addition on the various performance and emissions characteristics of interest. Also, the selection of Φ_c has the added feature of allowing for easier comparison of Type 0 results with the Type I and II results since only Φ_c was measured during the latter type tests. In addition, it is concluded from the above discussion that the methods of determining fuel-air ratios from gasoline-fueled engine exhaust gas composition (11) are also applicable to methanol blend levels up to 30%M to the same degree of accuracy.

III. A-2 MBT SPARK ADVANCE

Prior to performing the Type O Tests it was necessary to determine the MBT spark advance (SA) for the various blend levels at 2000 RPM and 16 in.Hg (54 kPa) manifold vacuum. To this end tests were carried out to obtain the brake thermal efficiency versus SA curves shown in Figure 5. Since the objective of these tests was to determine MBT SA and not absolute values of brake thermal efficiency, efficiency ratios $\eta/\eta_{51^\circ BTC}$ (where $\eta_{51^\circ BTC}$ is the efficiency measured at 51°BTC SA) rather than absolute values of efficiency η are presented. The efficiency at 51°BTC was arbitrarily chosen as the reference value, for this was the SA selected for the "standard" conditions operating condition described in Section II. E-1. Each of the curves in Figure 5 is for a combination of blend level and average equivalence ratio as specified in the Figures. For example, Figure 5a is for 0%M (Indolene) at $\Phi_c \approx 0.865$; Figure 5b for 20%M at $\Phi_c \approx 0.857$; all such Figures are for 2000 RPM and 16 in.Hg (54 kPa).

For each combination of blend level and equivalence ratio the MBT SA point is identified by an X on the curves in Figure 5. The so defined values of MBT SA and the corresponding value of equivalence ratio are plotted for all the blends in Figure 6. Also on the curves in Figure 5 are points labeled Y. These Y points correspond to the dashed curve best estimate of MBT SA shown in Figure 6. From Figure 6 it is concluded that for Indolene and up to 30%M blend-fueled operation at 2000 RPM and 16 in.Hg, the MBT SA is the same over the range of equivalence ratio $0.85<\Phi_c<1.14$.

In Figure 5 it is noted that as the spark is retarded from the MBT value, the efficiency tends to decrease rather rapidly. Therefore, to insure operation at close-to-peak efficiency, the spark advances used in the Type O tests were those identified by the solid curve in Figure 6. This curve is about 2 degrees advanced from the dashed curve best estimate of MBT SA. Thus the Type O tests were carried out at values of SA about 2 degrees advanced from MBT SA.

III. A-3 TORQUE

According to the format described in Section II. F-2, the performance characteristic torque data is presented in Figures 7, 8 and 9 for the 0, 20 and 30%M blends respectively. As expected, the torque as a function of equivalence ratio falls off rather rapidly as the mixture is made lean.

Within the imposed restriction of using only the regression model functional relationships given by Equations (1), (2) and (3) the second order function of Φ_c ($a_3 = b_3 = c_3 = 0$) was found to give the best fit. The Equation (1) regression curves which are shown in Figures 7, 8 and 9, are seen to give a good fit of the data except for equivalence ratios Φ_c greater than around 1.3. Over the range $0.79 < \Phi_c < 1.22$, however, the fit is good.

The Equation (1) regression curves for the 0, 20 and 30% blends are shown superimposed in Figure 10. It is observed that the 20% and 30% blends exhibit an identical increase in torque over that found for Indolene-fueled operation. The observed increase in torque is approximately 2%. As discussed below, this observed increase is statistically significant.

Table 5 summarizes the results of the Equations (2,3) regression analysis of the pooled 0, 20 and 30%M blend torque data. The $t_{i,j}$ values are large for all of the terms used in the Equations (2,3) regression models. The decision to include the methanol effect in the model, (either M or $M\Phi_c$) is significant at the tabulated values of $\alpha_{4,3}$ and $\alpha_{5,5}$.

The substantial reduction in the sum of squares of the deviation about regression resulting from the inclusion of the M or $M\Phi_c$ term in the model is further evidence of the significance of the methanol effect. Correspondingly, the F statistic for the lack of fit test of hypothesis is seen to be reduced substantially by introducing the M or $M\Phi_c$ effect in the model. Comparing the values of the lack of fit hypothesis test statistic, it is observed that the Φ_c term (F=1.15) gives a slightly better fit than the $M\Phi_c$ term (F=1.25) showing that the effect of methanol addition is about the same for all values of Φ_c.

In summary, the statistical analysis shows that methanol has a positive effect on engine torque. This is consistant with the observation made during engine testing of a definite torque increase on switching from Indolene to methanol blends. The torque increase does not appear to be a linear function of blend level. The increase for both the 20% and 30% blends was found to be approximately 2% of the torque measured during Indolene-fueled engine operation.

III. A-4 BRAKE THERMAL EFFICIENCY

Figures 11, 12 and 13 illustrate the brake thermal efficiency data for the 0, 20 and 30%M blends respectively. As expected the efficiency is a function of equivalence ratio with peak efficiency occurring on the lean side of stoichiometric. Also included in the Figures are the Equation (1) regression model curves. A satisfactory fit was found using all three Φ_c terms (viz. Φ_c, Φ_c^2 and Φ_c^3) over the range $0.87 \leq \Phi_c \leq 1.17$.

The regression curves for the three blend levels are superimposed in Figure 14. These curves show an increase in efficiency resulting from methanol addition. This increase is small and marginally significant from a statistical point of view as discussed below.

Table 6 summarizes the results of the Equations (2, 3) regression analysis of the pooled 0, 20 and 30%M efficiency data. The high t values and the corresponding low values of α show that all of the Φ_c terms (Φ_c, Φ_c^2, Φ_c^3) are significant. It should be noted, however, that the inclusion of the Φ_c^3 term gives only a slight improvement in fit as compared to the fit obtained with only the Φ_c and Φ_c^2 terms and is not necessary from a statistical point of view. The general shape of the cubic function, however, was more satisfactory and it was selected for both the Equation (1) and the Equations (2, 3) regression analyses.

The results given in Table 6 show that while the inclusion of the Φ_c and Φ_c^2 terms are significant at the 0.006 or less significance level and the Φ_c^3 term at the 0.019 or less significance level, the inclusion of the M or $M\Phi_c$

terms is significant at the 0.08 and 0.095 significance levels respectively. This means that the probability of making a Type I decision error, that is the probability of rejecting the null hypothesis: $b_4 = C_4 = 0$, when in fact they actually are zero is 0.08 and 0.095 respectively. In other words, if b_4 or c_4 is actually zero, then the probability of obtaining values of t equal to or greater than the values 1.8 and 1.7 given in Table 6 by chance is 0.08 and 0.095 respectively. Since the usually accepted maximum value of α is around 0.05 (that is, the decision rule for hypothesis testing is usually done at the 5% significance level), the statistical significance of including the M or $M\Phi_c$ term is marginal.

It is thus concluded that at the 5% significance level there is no effect of methanol addition on brake thermal efficiency. At the 8% significance level there is a positive methanol effect but it is small; the increase in efficiency for a 20% blend being about 1.3% of the Indolene-fueled operation efficiency at $\Phi_c = 1.0$. For the 30% blend level the increase in efficiency is disproportionately larger, being about 5% of the Indolene-fueled operation efficiency at $\Phi_c = 1.0$.

III. A-5 VOLUMETRIC EFFICIENCY

Figures 15, 16 and 17 illustrate the volumetric efficiency data for the 0, 20 and 30%M blends, respectively. Regression curves are not given in these Figures because over the range $0.87 \leq \Phi_c \leq 1.17$ the Equation (1) regression was found to be not significant. That is, over this range of Φ_c volumetric efficiency variations could not be explained or accounted for by the Equation (1) regression model. In fact, over this range, the average value of the volumetric efficiency for the 0, 20 and 30%M blends was 34.3, 34.4 and 34.2%, respectively, with corresponding standard deviations of 0.51, 0.45 and 0.43. It is thus concluded that over the range $0.87 \leq \Phi_c \leq 1.17$, the volumetric efficiency is not affected by the blend level for up to 30% methanol.

III. A-6 CARBON MONOXIDE MASS EMISSIONS

Figures 18, 19 and 20 illustrate the CO mass emission data for the 0, 20 and 30%M blends respectively, as well as the corresponding Equation (1) regression model curve. In the model all three terms Φ_c, Φ_c^2 and Φ_c^3 were used and the fit is very good. In Figure 21 the regression model curves for the three blend levels are superimposed. It is concluded that for $0.87 \le \Phi_c \le 1.17$ the CO mass emission for all three blend levels are identical and that methanol addition to Indolene has no effect on CO mass emission for up to 30% blend levels.

III. A-7 NITRIC OXIDE MASS EMISSIONS

Figures 22, 23 and 24 illustrate the NO_x mass emission data for the 0, 20 and 30% methanol blends, respectively. The cubic form of Equation (1) was found to give the best fit and the curves obtained are shown in these Figures as well as in Figure 25.

Shifts in the NO_x vs Φ_c curves, as illustrated in Figure 25 indicate a decrease in NO_x mass emissions with increasing blend levels. The first test to infer statistical significance of the M or $M\Phi_c$ term using the pooled 0, 20 and 30% blend data showed the inclusion of these terms to be significant at the 0.008 and 0.007 significance level as reflected by the α values given in Table 7. This strongly suggests that there is a methanol effect on NO_x emissions.

The second test for significance, the lack of fit test, did not give as strong an indication that the M or $M\Phi$ term was significant as reflected by the rather small decrease in the sum of squares of the deviation about regression found when the M or $M\Phi_c$ term was included in the regression analysis. This small decrease, however, is probably due to the inadequacy of the Equations (2, 3) regression model where the methanol dependence is assumed to be linear. Contrary to the model, Figure 25 shows the methanol effect to be non-linear. Had the proper non-linear M or $M\Phi_c$ effect been used in the Equations

(2, 3) model the decrease in lack of fit would have been greater. It was thus decided that the decrease in NO_x mass emissions, as reflected by Figure 25 is significant. The $M\Phi_c$ term was found to give slightly better correlation indicating that the methanol effect on NO_x emissions is somewhat greater for rich mixtures.

In conclusion, NO_x mass emissions were found to decrease with methanol addition. The decrease was not proportional to the methanol blend level; for operation at $\Phi_c = 1$, with the 20%M blend the decrease was about 5.4% of the NO_x mass emission level found for Indolene-fueled operation, for the 30% blend, at $\Phi_c = 1$, the corresponding decrease was about 14.5%. For operation at $\Phi_c = 1.1$ the decreases were approximately 6.7% for the 20% blend and 14.7% for the 30% blend.

III. A-8 FID TOTAL HYDROCARBON MASS EMISSIONS

The FID total HC mass emission data are shown in Figures 26, 27 and 28. The linear portion of the Equation (1) regression model was found to give a satisfactory fit of the data. The resulting regression lines are also shown in Figures 26, 27 and 28. The regression lines are superimposed in Figure 29 and show a decrease in FID HC mass emissions for increasing blend levels. This decrease was found to be statistically significant.

In Table 8 the significance level of including the Φ_c or $M\Phi_c$ term is seen to be less than 0.001; a strong indication that the Figure 29 decrease in FID HC mass emissions with increasing methanol content is statistically significant. In addition the lack of fit test statistic F and the sum of squares of the deviation about regression are found to undergo substantial reductions when the M or $M\Phi_c$ term is included in the Equations (2, 3) regression model.

In summary it is concluded that the addition of methanol to Indolene decreases FID total HC mass emissions. The decrease is about 8% of the Indolene-fueled operation mass emission level for the 20% blend; the corresponding decrease is about

20% for the 30% blend.

III. A-9 CARBON DIOXIDE MASS EMISSIONS

Figures 30-32 illustrate the CO_2 mass emission data and the Equation (1) regression model curves. The superimposed curves in Figure 33 indicate that there is a methanol effect on CO_2 mass emissions with the CO_2 decreasing with increasing methanol content. Results of the Equations (2, 3) regression analysis given in Table 9 shows that the effect is statistically significant. The quadratic function with the M term (Function 3) is seen to give the best fit.

III. A-10 OXYGEN MASS EMISSIONS

Figures 34 through 37 illustrate the O_2 mass emission data and the regression curves. It is observed that oxygen mass emissions are unaffected by the methanol blend level.

III. A-11 GEOMETRIC DISTRIBUTION

Geometric (cylinder-to-cylinder) fuel-air ratio distribution was determined by placing 0.25 in. (0.635 cm) outside diameter, stainless steel tubing, exhaust gas sampling probes in close proximity to each of the exhaust valves and monitoring the exhaust gas oxygen concentration. In Figure 38 the individual cylinder, exhaust gas oxygen emission levels data are shown as a function of methanol blend level for two equivalence ratios: one near stoichiometric, $\Phi_c \approx 0.97$; the other for lean operation $\Phi_c \approx 0.87$. As with the rest of the Type 0 test points, the operating conditions were 2000 RPM, 16 in. Hg (54 kPa) and MBT spark advance. Note that the average of the individual cylinder oxygen emission levels is greater than the oxygen emission level corresponding to the Φ_c values (0.97 and 0.87) as shown in Figures 39, 40 and 41, which were measured downstream of the exhaust manifold. This difference in oxygen level is due to oxidation reactions occurring downstream of the individual cylinder exhaust gas sampling probe locations.

In order to estimate the individual cylinder fuel-air equivalence ratios from the data in Figures 39, 40 and 41 it was therefore necessary to correct the individual cylinder oxygen emission levels. The correction involved multiplying each of the individual cylinder oxygen emission levels by the mixed, blend-averaged oxygen emission level and dividing by the individual cylinder averaged oxygen emission level. The equivalence ratios thus determined are illustrated in Figure 42 for $\Phi_c \approx 0.97$ and in Figure 43 for $\Phi_c \approx 0.87$. In each Figure the average value of the individual cylinder equivalence ratios is equal to the corresponding value of $\Phi_c = 0.97$ for Figure 42 and 0.87 for Figure 43.

The inability of the intake system to deliver the same fuel-air mixture to each cylinder is reflected by the cylinder to cylinder variation in equivalence ratio as is illustrated in Figures 42 and 43. The rear cylinders, 3 and 4, operate at richer than the average equivalence ratio while the front cylinders operate lean. Methanol addition is observed to affect the distribution pattern with the richest cylinder, 3, becoming richer and the leanest cylinder, 1, becoming leaner. The difference in equivalence ratio between the richest and leanest cylinder increases with blend level as shown in Figure 44. The increase is probably due to the increased latent heat of vaporization and increased fuel mass flow rate for the blends. A confounding effect is that during the experiments it was necessary to make adjustments to the throttle position to attain the required Type 0 test operating conditions when blend levels were changed. The adjustments, however, were very slight and it is suspected that the observed changes in distribution are due mainly to the methanol blend level per se and not throttle position.

In summary, it is concluded that, at the Type 0 tests operating conditions, methanol addition to gasoline has a detrimental effect on geometric distribution. With Indolene-fueled operation the spread in fuel-air equivalence ratio between the richest and the leanest cylinder was about 0.05. The spread increases nearly linearly with blend level at a rate of approximately 0.01 equivalence ratios per 10%M.

III. B TYPE I TESTS

Sections labeled III. B describe the performance and emissions characteristics measured during the Type I tests during which 10, 20 and 30% methanol blends were substituted for Indolene while making no engine or dynamometer control adjustments. Testing was carried out with the engine adjusted to simulate 52 mph (83 km/hr) cruise and acceleration. Table 10 identifies the Indolene-fueled operation values of the engine parameters; detailed information is given in Table 3 for all of the Type I test data points.

III. B-1 FUEL-AIR EQUIVALENCE RATIO

The reduction in fuel-air equivalence ratio that occurs when blends are substituted for Indolene with no adjustment to the engine is illustrated in Figure 45. Multiple linear regression analysis showed that the blend leaning effect was the same for both the 52 mph cruise and 52 mph acceleration tests.

III. B-2 TORQUE, ENGINE SPEED

Figure 46a shows the effect of methanol blend level on torque for the Type I tests. For both the 52 mph cruise and acceleration tests there is a decrease in torque with increasing blend level. Since the water flow control valve to the dynamometer was not changed upon switching to the blends there was a corresponding reduction in engine speed. The reduction is illustrated in Figure 46b.

III. B-3 BRAKE THERMAL EFFICIENCY

Brake thermal efficiency is plotted as a function of methanol blend level for the Type I tests in Figure 47. For the Indolene-fueled operation 52 mph cruise condition efficiency rises with methanol blend level for blend levels up to around 20%M. For the higher blend level the efficiency appears to decrease. Insufficient 52 mph acceleration data were taken to detect trends but there appears to be an increase in efficiency with increasing blend level.

III. B-4 CARBON MONOXIDE EMISSIONS

The CO emission data for the Type I tests are illustrated in Figure 48. The effect of blend level on CO emissions is a function of the fuel-air equivalence ratio for the Type I tests 0%M condition: If the mixture is rich during Indolene-fueled operation there is a significant decrease in CO emissions when the blends are substituted; if the mixture is lean substitution of the blends results in much smaller changes in CO emissions. The reader is referred to Section III. C-5 for a detailed explanation.

III. B-5 NITRIC OXIDE EMISSIONS

Nitric oxides were found to decrease with increasing methanol blend level for the Type I tests. Figure 49 is used to illustrate the reduction.

III. B-6 FID TOTAL HYDROCARBON MASS EMISSIONS

Flame Ionization Detector Hydrocarbon volume and mass emissions are shown as a function of blend level for the Type I tests in Figures 50a and b. A decrease in emissions is noted. The decrease tends to level off at around 30%M. In Figure 50c the FID HC mass emissions are presented as a function of equivalence ratio. It is noted that there is a strong correlation between the emission level and the equivalence ratio. In Figure 50c it is observed that the 30% blend mode of operation equivalence ratio is near the lean misfire limit when HC emissions start to rise with decreasing Φ_C. This explains why the HC emissions reduction tends to taper off in Figures 50a and b at 30%M.

III. C TYPE II TESTS

In Sections labeled III. C the effects of methanol addition to gasoline on performance and emissions characteristics when the engine is operated at equal to Indolene-fueled operation torque and engine speed (Type II tests) are described. In the Figures used to illustrate the effects, the various operating conditions are identified by the nominal values of vehicle speed and load level (cruise or acceleration) which corresponds to the engine speeds and torques given in Table 10.

III. C-1 MANIFOLD VACUUM

In order to achieve the same torque and engine speed with the blends as had been measured during Indolene-fueled operation it was necessary to open the throttle. Figure 51 shows the resulting manifold vacuums. As the blend level is increased, increasingly greater manifold pressure (less vacuum) was needed to achieve equal-to-Indolene fueled power output. The required manifold vacuum decrease for the blends appears to be independent of the simulated vehicle speed and load, being on the average 0.8 in. Hg (2.7 kPa) for the 20% blend.

III. C-2 BLEND LEANING EFFECT

One consequence of adding methanol to gasoline is the "blend leaning effect" (3). This effect is illustrated in Figure 52 where the fuel-air equivalence ratio is plotted as a function of methanol blend level. As the blend level increases the equivalence ratio is seen to decrease.

III. C-3 BRAKE THERMAL EFFICIENCY

Figure 53 illustrates the brake thermal efficiency data. It is observed that, for the particular set of conditions given in Table 10 for Indolene-fueled operation, the brake thermal efficiency increases when the engine is fueled with methanol blends at the same torque and engine speed and with the spark advance adjusted to the values given in Table 3.

There are a number of possible reasons that can be given as to why the efficiency should change as the blend level increases (3). It should be pointed out, however, that the spark advance during Indolene-fueled operation was advanced approximately 10 deg from MBT while the spark advance for the 10 and 20% blend level mode of operation was about 6 degrees advanced and 1 degree retarded from MBT spark advance respectively. This deviation from MBT spark advance for Indolene-fueled operation places the Indolene fuel at a disadvantage with regards to brake thermal efficiency comparisons.

III. C-4 OXYGEN EMISSIONS

As a result of the blend leaning effect oxygen emissions increase as the methanol blend level is increased. To illustrate this increase Figure 54 is presented.

III. C-5 CARBON MONOXIDE EMISSIONS

Carbon monoxide emission data for the Type II tests are shown in Figure 55. A large scatter is observed for the Indolene-fueled (0%M) mode of operation. In fact there were two 0%M-fueled operating test points at 40 mph (64 km/hr) cruise, numbered 126 and 130, which exhibited very large levels of CO (see Table 3) and are not included in the Figure.

There is a reason for the scatter in CO emissions which can be explained by considering Figure 56a where the CO volume emissions are plotted as a function of fuel-air equivalence ratio, Φ_c, for the 0%M data. For convenience the data points have been identified by their corresponding Test Point Number in the Figures. From Figure 56a it is observed that there were test-to-test variations in Φ_c for the 0%M-fueled mode of operation. In addition it is observed that the equivalence ratios for the 0%M blend level Type II tests are in close proximity to the "critical" fuel-air equivalence ratio $\Phi_c \approx 0.95$ which separates the lean region of operation ($\Phi \lesssim 0.95$) where the CO emissions were found to be independent of Φ_c and the richer region ($\Phi_c \gtrsim 0.95$) where the CO emissions were found to rise with increasing Φ_c (See Figure 18). There is a good correlation between the observed scatter in the Figure 55a CO emissions, including Test Points numbered 126 and 130, and the equivalence ratio as shown in Figure 56a. Similar scatter was not observed for the methanol blends because the equivalence ratios for the blends were all on the lean side of the "critical" equivalence ratio $\Phi \approx 0.95$ where CO emissions were found to be independent of Φ_c (Figure 18).

Another phenomenon regarding the CO emissions was observed during the 0%M-blend fueled Type II tests. This phenomenon is illustrated in Figure 56b where the CO NDIR analyzer output, as obtained from the strip-chart recorder, is presented. Test points numbered 139 through 144 are included in the Figure; they were all taken on the same day, consecutively, and without engine shut-down. For tests numbered 139 through 143 the amplitude of the unsteadiness in the response of the analyzer is essentially the same, there being slight changes in the average response as reflected by the slight variations in volume % CO shown in Figure 55a. For test point number 144, however, Figure 56b shows a larger amplitude of unsteadiness. There is also a marked increase in the average instrument response for this test point as is reflected by the increase in CO emissions in Figure 55a. This phenomenon of increased CO emission level with increasing amplitude of the unsteadiness in the CO analyzer response was also noted for other tests with the 0%M blend level. While it is not known for certain, it is suspected that the large amplitude of unsteadiness in CO analyzer response for the richer mixtures is caused by time or cycle-to-cycle variations in the engine operating conditions. This variation in engine operating conditions could have resulted from the engine running on both sides of the "critical" value of Φ_c with subsequent variations in CO emissions. Such large variations in CO emissions do not occur for the leaner mixtures because cycle-to-cycle variations in engine operating conditions do not raise the equivalence ratio above the "critical" value. Instead the engine cycles in the region ($\Phi \lesssim 0.95$) where CO emissions are independent of Φ_c.

It is apparent from the above discussion and the data given in Figures 55 and 56 that the effect of methanol blend level on the CO emissions for the Type II tests depends on the operating condition with Indolene. For Indolene fueled operation at Φ_c less the "critical" value of approximately 0.95 the blend level does not appear to affect the CO volume emissions for the 30 and 40 mph cruise tests. (Figure 55a). For the 52 mph cruise and acceleration tests there appears to be a slight increase in CO volume emissions; approximately

0.01% CO per 10%M. The CO mass emissions on the other hand increase with increasing methanol blend level for all of the speeds and loads with the increase appearing to be greater as the speed and load increase.

For Indolene-fueled operation at Φ_c greater than the "critical" value of approximately 0.95 there is a decrease in both CO mass and volume emissions when a 10% blend is substituted. A reason for this decrease in CO emissions is the reduction in Φ_c to values lower than the "critical" value of 0.95. Whether the CO mass emission will eventually increase above the Indolene fueled value as the methanol blend level is increased depends on the speed, load and the initial Indolene-fueled value of Φ_c as can be seen by studying Figure 55b.

III. C-6 NITRIC OXIDE EMISSIONS

Nitric oxide (NO_x) mass emission data for the Type II tests are illustrated in Figure 57. It is observed that for all of the speeds and loads there is a decrease in NO_x emissions as the methanol blend level is increased.

III. C-7 FID TOTAL HC EMISSIONS

FID total HC mass emission data for the Type II tests are shown in Figure 58. As the blend level increases the emissions are seen to decrease. This is consistent with the results obtained during the Type 0 tests where the FID total HC mass emissions were found to decrease with increasing methanol blend level and with decreasing equivalence ratio, Φ_c (Figure 29). It is of interest to note that for the 30%M blend the equivalence ratio for the Type II tests was around 0.8. This value of equivalence ratio is near the lean misfire limit observed during the Type 0 tests which were performed at operating conditions close to those of the 52 mph cruise Type II tests. Had higher blend levels been tested during the Type II tests it is expected that misfire would have been encountered with subsequent increase in FID total HC emissions.

IV. SUMMARY AND CONCLUSIONS

For one phase of the study (Type O Tests) a multicylinder, carbureted engine was fueled with blends of 0, 20 and 30 volume percent methanol in a base stock representative of unleaded gasoline (viz. Indolene). The engine was operated under steady state conditions at constant speed, manifold vacuum and MBT spark advance over a range of fuel-air equivalence ratios. Comparisons were then made of performance and emissions characteristics for the various blends at equal equivalence ratios. At the same engine speed (2000 RPM), manifold vacuum [16 in. Hg (54 kPa)], MBT spark advance and equivalence ratio [over the range $(0.87 \leq \Phi_c \leq 1.17)$] i.e. for Type O Tests operating conditions:

1. The MBT spark advance was the same for all of the blend levels tested (0, 20, 30%M).
2. The 20 and 30%M blends produced the same torque with the value being approximately 2% greater than the Indolene-fueled torque value.
3. At the 5% significance level there was no effect of methanol addition on brake thermal efficiency. (See note after conclusion 10).
4. Volumetric efficiency was not affected by the blend level.
5. Carbon monoxide emissions were not affected by the blend level.
6. Nitric oxide (NO_x) mass emissions were found to decrease with increasing blend level. The decrease was not proportional to the blend level. At $\Phi_c = 1.0$ the 20%M blend exhibited a 5.4% decrease; the 30%M blend a 14.5% decrease. At $\Phi_c = 1.1$ the decrease was 6.7% for the 20%M blend and 14.7% for the 30%M blend.
7. FID HC mass emissions decreased with increasing blend level. The decrease was about 8% of the Indolene-fueled operation mass emission level for the 20%M blend and about 20% for the 30%M blend.

8. Carbon dioxide mass emissions were found to decrease with increasing blend level.

9. Oxygen mass emissions were not affected by the blend level.

10. For near stoichiometric ($\Phi_c \approx 0.97$) and lean operation ($\Phi_c \approx 0.87$) methanol addition was found to have a detrimental effect on geometric (cylinder-to-cylinder) fuel-air ratio distribution. The difference in fuel-air equivalence ratio between the richest and leanest cylinder was about 0.05 equivalence ratios for Indolene-fueled operation. The difference increased nearly linearly with blend level at the ratio of about 0.01 equivalence ratios per 10%M.

It was also found that the methods used for determining fuel-air equivalence ratios from exhaust gas analysis during gasoline-fueled operations are also applicable, to the same degree of accuracy, for up to 30%M blends.

NOTE The conclusion regarding brake thermal efficiency for the Type O Tests depends on the values chosen for the lower heating value of Indolene and methanol. Consider an engine operated at a given speed, with a stoichiometric mixture, and fueled by Indolene and methanol blends. If the volumetric efficiency is the same during Indolene and blend fueled operation (Conclusion 4) then

$$\frac{\eta_B}{\eta_I} = \frac{T_B}{T_I} \quad \frac{LHV_I}{LHV_B} \quad \frac{SFA_I}{SFA_B}$$

where η is brake thermal efficiency, T is torque, LHV is lower heating value, SFA is stoichiometric fuel-air ratio and the subscripts I and B denote Indolene and methanol blend respectively. Assuming a 2% increase in torque for both 20 and 30% blend fueled operation (Conclusion 2) and estimating LHV_I and LHV_B from LHV_I and LHV_B values presented by other investigators the equation above yields values of η_B/η_I ranging between 1.014 and 1.018 for 20%M and between 1.011 and 1.016 for 30%M. Thus, at best, efficiency gains of 1.8% and 1.6% can be expected based on conclusions 2 and 4, and published values of LHV_I and LHV_B for 20 and 30%M blends respectively.

During another phase of the study, experiments (Type II Tests) were performed to determine the effect of methanol addition to unleaded gasoline (Indolene) on the performance and emissions characteristics of the same carbureted engine if it were in a stock condition and used to power an automobile. Engine torque and speeds selected simulated 30, 40 and 52 mph cruise (48, 64 and 84 km/hr) as well as a higher value of torque (corresponding to an accelerating condition) at the 52 mph (84 km/hr) speed. The results of these experiments showed the following:

1. When 20 and 30%M blends were substituted for gasoline with no engine adjustments the torque and engine speed decreased.
2. In order to regain the Indolene-fueled operation values of torque and engine speed it was necessary to lower the manifold vacuum by opening the throttle. The required manifold vacuum decrease was practically independent of the simulated vehicle speed and load condition.
3. The fuel-air equivalence ratio with the blends was found to be lower than that found during Indolene-fueled operation. With the 30%M blend the mixture was observed to have an equivalence ratio of around 0.8 which is close to the lean misfire limit.
4. The brake thermal efficiency during blend-fueled operation was found to be greater than that during Indolene-fueled operation. Part of the increase was attributed to the spark advance being closer to the MBT value during blend-fueled operation.
5. The effect of blend level on CO emissions was found to depend on the Indolene-fueled value of fuel-air equivalence ratio. When the Indolene-fueled operation fuel-air mixture was richer than $\Phi_c \approx 0.95$ methanol addition was found to decrease CO emissions. For Indolene-fueled operation at $\Phi_c \overset{\sim}{<} 0.95$ there was no significant effect of methanol blend level on CO emissions at the 30 and 40 mph

(48, 64 km/hr) cruise simulation condition; a slight increase in CO emissions, however, was observed for the 52 mph (84 km/hr) cruise and acceleration simulation.

6. Nitric oxide (NO_x) emissions were found to decrease substantially with increasing methanol blend level.

7. FID hydrocarbon emissions were also found to decrease with methanol addition. The rate of decrease with methanol addition appeared to approach zero at around the 30%M blend level operating condition which is in close proximity to the lean misfire limit.

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LIST OF TABLES

TABLE	TITLE	PAGE
1	Measuring Instrumentation	40
2	"Standard" Test Conditions	41
3	Performance and Emissions Characteristics Data	42
4	Statistical Significance of Test Results - FORMAT	79
5	Statistical Significance of Test Results - TORQUE	80
6	Statistical Significance of Test Results - BRAKE THERMAL EFFICIENCY	81
7	Statistical Significance of Test Results - NITRIC OXIDES (NO_x) MASS EMISSIONS	82
8	Statistical Significance of Test Results - FID TOTAL HC MASS EMISSIONS	83
9	Statistical Significance of Test Results - CARBON MONOXIDE MASS EMISSIONS	84
10	Nominal Values of Operating Parameters for Type I and II Tests with Indolene Fuel	85

Table 1 Measuring Instrumentation

Variable	Method	Instrument Accuracy*
Air Flow	Long-Radius Flow Nozzle	±2%
Fuel Flow	Rotameter	±1% calibrated for 0,20,30% M blends
Manifold Vacuum	Mercury Manometer	±0.05 in Hg (±0.17 k PA)
Spark Advance	Timing Light	±1 deg.
Engine Speed	Strobotac	±10 RPM
Torque	Dynomometer Load Cells	±0.5 ft lb_f calibrated during investigation
CO	NDIR Analyzer (Span gas calibration)	±1%
CO_2	NDIR Analyzer (Span gas calibration)	±1%
O_2	Polarographic Analyzer (Room air calibration)	±1%
NO_x, NO	Chemiluminescent Analyzer (Heated sample, span gas calibration)	±1%
Total HC	FID Analyzer (Heated sample, span gas calibration)	±1%
Wet, Dry Bulb Temp.	Mercury in Glass Thermometer	±0.5°F
Engine Temps.	Chromel-Alumel Thermocouples	±0.5°F
Barometric Pressure	U.S. National Weather Service, University of Miami	

* From manufacturers specifications and/or estimates from calibration during the investigation. See Section II. D-2 for a discussion of experimental uncertainty of the various measurements.

Table 2 "Standard" Conditions

FUEL	INDOLENE
SPARK ADVANCE	51° BTDC
MANIFOLD VACUUM	16 in. Hg (54 kPa)
TORQUE	47 ft lb_f (64 N·m)
ENGINE SPEED	2000 RPM
EXHAUST GAS OXYGEN	1.35 VOLUME PERCENT
WATER COOLANT INLET	173°F (78°C)
WATER COOLANT OUTLET	189°F (87°C)

TABLE 3

PERFORMANCE AND EMISSIONS CHARACTERISTICS DATA *

* Table entries with lines through them are invalid as a result of a measurement not being taken or a measurement not being correct due to instrument failure. Brake horse power and brake mean effective pressure values are corrected to standard conditions [12].

TEST NO.	90	91	92	93	94	95	96	97	98	99
% METH.	.00	10.00	20.00	20.00	10.00	20.00	.00	10.00	20.00	10.00
SPARK ADV. DEG. BTDC	31.0	51.0	51.0	51.0	51.0	51.0	34.0	34.0	34.0	34.0
MAN. VAC. INCH.HG.	16.00	15.70	15.50	15.30	15.60	15.30	10.00	9.85	9.80	9.60
TORQUE FT. LBS.	46.50	45.00	44.00	46.50	46.50	46.50	86.50	85.00	84.00	85.50
ENG. SPEED R.P.M.	2000.00	1900.00	1880.00	2000.00	2000.00	2000.00	2000.00	1960.00	1920.00	2000.00
EQ. RATIO FUEL/AIR	~~7.243~~	~~6.791~~	~~6.256~~	~~6.873~~	~~7.209~~	~~6.873~~	~~10.759~~	~~10.219~~	~~9.495~~	~~10.470~~
F/A STOICH	.0689	.0733	.0781	.0781	.0733	.0781	.0689	.0733	.0781	.0733
B.S.F.C. LBS/HP HR	.6644	.7204	.7315	.7148	.7031	.7148	.5305	.5563	.5694	.5553
COR B.H.P.	17.28	15.68	15.37	17.28	17.28	17.28	32.14	30.95	29.96	31.76
COR. BMEP. P.S.I.	34.73	33.61	32.86	34.73	34.73	34.73	64.60	63.48	62.73	63.85
VOL. EF. %	~~4.75~~	~~5.01~~	~~5.06~~	~~4.76~~	~~4.76~~	~~4.76~~	~~4.76~~	~~4.85~~	~~4.96~~	~~4.76~~
B.TH.E. %	20.16	19.74	20.70	21.19	20.23	21.19	25.25	25.57	26.60	25.61
% O2	1.25	3.20	3.80	4.20	3.20	3.80	1.80	3.00	3.50	3.05
% CO	.1814	.1895	.1976	.1895	.1935	.1976	.1697	.1895	.1935	.1935
% CO2	13.90	12.60	12.20	11.90	12.80	12.30	13.70	13.00	12.40	12.90
% CH3OH	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~
% HCHO	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~
NO. PPM W.	3600.0	2600.0	2000.0	1750.0	2300.0	1950.0	3400.0	2350.0	1850.0	2400.0
NO2 PPM W	~~.0~~	300.0	300.0	150.0	300.0	~~.0~~	~~.0~~	150.0	250.0	~~.0~~
NOX PPM W	3600.0	2900.0	2300.0	1900.0	2600.0	1950.0	3400.0	2500.0	2100.0	2400.0
HC PPM W	1500.0	800.0	700.0	550.0	675.0	600.0	800.0	400.0	400.0	400.0
MASS O2 GRMS/HP HR	61.033	176.110	205.285	227.649	169.372	199.182	71.640	124.071	145.297	126.829
MASS CO GRMS/HP HR	7.752	9.123	9.340	8.985	8.962	9.062	5.909	6.856	7.029	7.041
MASS CO2 GRMS/HP HR	933.196	953.470	906.223	886.882	931.544	886.489	749.737	739.259	707.802	737.586
MASS NOX GRMS/HP HR	19.600	17.750	14.052	11.317	15.426	10.818	14.305	11.290	9.824	10.551
MASS HC GRMS/HP HR	3.580	2.144	1.847	1.452	1.743	1.538	1.555	.809	.813	.812
EQ.R.CHM.	.954	.860	.834	.815	.862	.835	.923	.869	.845	.866
TEST NO.	90	91	92	93	94	95	96	97	98	99

PAGE 2

TEST NO.	90	91	92	93	94	95	96	97	98	99
DATE	5.21	5.21	5.21	5.21	5.21	5.21	5.21	5.21	5.21	5.21
HC PPM D	1693.1	899.4	789.5	618.6	760.3	677.4	902.1	451.5	452.1	451.1
NOX PPM D	4603.3	3200.4	2594.0	2137.1	2928.7	2201.5	3833.9	2821.6	2373.4	2706.5
DRY B TEMP DEG.F.	85.5	85.5	85.5	85.5	85.5	85.5	85.5	85.5	85.5	85.5
WET B TEMP DEG.F.	74.5	74.5	74.5	74.5	74.5	74.5	74.5	74.5	74.5	74.5
BAR.PRESS. INCH. HG.	29.75	29.75	29.75	29.75	29.75	29.75	29.75	29.75	29.75	29.75
IN.COOL.T. DEG.F.	~~256.0~~	~~252.0~~	~~252.0~~	~~256.0~~	~~257.0~~	~~256.0~~	~~259.0~~	~~257.0~~	~~256.0~~	~~258.0~~
OUT.COOL.T. DEG.F.	~~273.0~~	~~270.0~~	~~274.0~~	~~269.0~~	~~271.0~~	~~269.0~~	~~277.0~~	~~275.0~~	~~274.0~~	~~276.0~~
EXH.PRESS. P.S.I.	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~
AIR FLOW LBS/HR	~~23.58~~	~~23.58~~	~~23.58~~	~~23.58~~	~~23.58~~	~~23.58~~	~~23.58~~	~~23.58~~	~~23.58~~	~~23.58~~
FUEL FLOW LBS/HR	11.77	11.73	11.53	12.66	12.45	12.66	17.48	17.65	17.49	18.09
EXH. TEMP. CYL.NO. 1	~~1147.0~~	~~1077.0~~	~~1054.0~~	~~1091.0~~	~~1102.0~~	~~1088.0~~	~~1202.0~~	~~1145.0~~	~~1139.0~~	~~1186.0~~
CYL.NO. 2	~~.0~~	~~.0~~	~~.0~~	~~.0~~	~~.0~~	~~.0~~	~~.0~~	~~.0~~	~~.0~~	~~.0~~
CYL.NO. 3	~~1135.0~~	~~997.0~~	~~985.0~~	~~1017.0~~	~~1021.0~~	~~1016.0~~	~~1140.0~~	~~1139.0~~	~~1098.0~~	~~1138.0~~
CYL.NO. 4	~~1101.0~~	~~1023.0~~	~~1021.0~~	~~1052.0~~	~~1056.0~~	~~1036.0~~	~~1175.0~~	~~1134.0~~	~~1120.0~~	~~1097.0~~
INT.MAN.T. CYL.NO.1,2	~~195.0~~	~~227.0~~	~~184.0~~	~~178.0~~	~~181.0~~	~~178.0~~	~~193.0~~	~~180.0~~	~~177.0~~	~~179.0~~
CYL.NO.3,4	~~209.0~~	~~173.0~~	~~194.0~~	~~180.0~~	~~195.0~~	~~190.0~~	~~204.0~~	~~193.0~~	~~186.0~~	~~189.0~~
CARB. BASE	~~168.0~~	~~175.0~~	~~169.0~~	~~167.0~~	~~169.0~~	~~169.0~~	~~187.0~~	~~172.0~~	~~168.0~~	~~171.0~~
NO.D.MOLES PER.MOLE F	49.120	41.959	34.506	35.430	41.349	34.262	50.144	40.833	34.063	41.131
NO.M.W./D.	1.1287	1.1243	1.1278	1.1248	1.1264	1.1290	1.1276	1.1287	1.1302	1.1277
TEST. NO.	90	91	92	93	94	95	96	97	98	99

TEST NO.	100	101	102	103	104	105	106	107	108	109
% METH.	20.00	.00	10.00	20.00	30.00	30.00	20.00	10.00	.00	10.00
SPARK ADV. DEG. BTDC	34.0	51.0	51.0	51.0	51.0	51.0	51.0	51.0	34.0	34.0
MAN. VAC. INCH.HG.	9.20	16.00	15.80	15.65	15.30	14.40	15.40	15.80	10.00	9.90
TORQUE FT. LBS.	90.00	46.50	46.00	44.00	42.00	46.00	46.00	46.00	89.50	88.50
ENG. SPEED R.P.M.	2000.00	2000.00	1950.00	1900.00	1780.00	2020.00	2000.00	2000.00	2000.00	1960.00
EQ. RATIO FUEL/AIR	~~10.142~~	~~7.018~~	~~6.574~~	~~6.136~~	~~5.627~~	~~6.776~~	~~6.749~~	~~6.827~~	~~14.597~~	~~9.982~~
F/A STOICH	.0781	.0689	.0733	.0781	.0836	.0836	.0781	.0733	.0689	.0733
B.S.F.C. LBS/HP HR	.5686	.6483	.6598	.7149	.7844	.7599	.7144	.6778	.5086	.5256
COR B.H.P.	31.95	17.25	16.64	15.51	13.87	17.24	17.07	17.07	33.21	32.18
COR. BMEP. P.S.I.	64.23	34.68	34.31	32.81	31.32	34.31	34.31	34.31	66.75	66.00
VOL. EF. %	~~4.76~~	~~4.78~~	~~4.90~~	~~5.03~~	~~5.37~~	~~4.73~~	~~4.78~~	~~4.78~~	~~4.78~~	~~4.88~~
B.TH.E. %	20.63	20.66	21.23	21.18	20.62	21.29	21.20	20.98	26.34	27.06
% O2	3.60	1.50	2.50	3.80	5.15	5.10	3.90	2.70	1.20	2.10
% CO	.1935	.1620	.1775	.1935	.2017	.2143	.2059	.1814	.3581	.1775
% CO2	12.50	14.00	13.20	12.30	11.40	11.40	12.20	13.20	13.90	13.60
% CH3OH	~~.0~~	~~.0~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~
% HCHO	~~.0~~	~~.0~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~
NO. PPM W.	2000.0	3900.0	3700.0	2150.0	1000.0	900.0	1100.0	3400.0	3450.0	3200.0
NO2 PPM W	~~.0~~	~~.0~~	~~.0~~	400.0	~~.0~~	~~.0~~	~~.0~~	~~.0~~	~~.0~~	200.0
NOX PPM W	2000.0	3900.0	3700.0	2550.0	1000.0	900.0	1100.0	3400.0	3450.0	3400.0
HC PPM W	320.0	1500.0	1000.0	800.0	750.0	600.0	650.0	850.0	1150.0	750.0
MASS O2 GRMS/HP HR	149.172	71.000	122.121	198.910	297.260	285.292	205.737	133.590	44.420	78.334
MASS CO GRMS/HP HR	6.909	6.715	7.586	8.863	10.188	10.489	9.503	7.855	11.600	5.793
MASS CO2 GRMS/HP HR	707.417	911.936	886.399	885.279	904.767	876.853	884.933	898.024	707.476	697.544
MASS NOX GRMS/HP HR	8.701	19.504	19.144	15.306	6.100	5.322	6.136	17.822	13.533	13.907
MASS HC GRMS/HP HR	.645	3.470	2.390	2.047	2.114	1.639	1.675	2.058	2.084	1.374
EQ.R.CHM.	.842	.943	.893	.835	.778	.779	.833	.884	.959	.910
TEST NO.	100	101	102	103	104	105	106	107	108	109

PAGE 2

TEST NO.	100	101	102	103	104	105	106	107	108	109
DATE	5.21	5.23	5.23	5.23	5.23	5.23	5.23	5.23	5.23	5.23
HC PPM D	362.0	1694.2	1120.8	903.0	845.4	676.5	733.2	960.5	1299.9	850.5
NOX PPM D	2262.7	4405.0	4180.4	2878.3	1127.2	1014.7	1240.7	3842.2	3899.6	3855.8
DRY B TEMP DEG.F.	65.5	84.0	84.0	84.0	84.0	84.0	84.0	84.0	84.0	84.0
WET B TEMP DEG.F.	74.5	72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0
BAR.PRESS. INCH. HG.	29.75	29.75	29.75	29.75	29.75	29.75	29.75	29.75	29.75	29.75
IN.COOL.T. DEG.F.	~~238.0~~	175.0	173.0	170.0	169.0	172.0	175.0	175.0	176.0	175.0
OUT.COOL.T. DEG.F.	~~275.0~~	190.0	186.0	183.0	182.0	185.0	188.0	188.0	194.0	191.0
EXH.PRESS. P.S.I.	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~
AIR FLOW LBS/HR	~~23.00~~	~~23.74~~	~~23.74~~	~~23.74~~	~~23.74~~	~~23.74~~	~~23.74~~	~~23.74~~	~~23.74~~	~~23.74~~
FUEL FLOW LBS/HR	10.03	11.48	11.44	11.38	11.17	13.45	12.52	11.88	17.34	17.36
EXH. TEMP. CYL.NO. 1	~~1194.0~~	1059.0	1027.0	990.0	953.0	1007.0	1013.0	1037.0	1034.0	1096.0
CYL.NO. 2	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~
CYL.NO. 3	~~1095.0~~	975.0	949.0	899.0	863.0	926.0	915.0	929.0	1034.0	990.0
CYL.NO. 4	~~1069.0~~	999.0	971.0	946.0	902.0	967.0	952.0	970.0	1077.0	1043.0
INT.MAN.T. CYL.NO.1,2	~~176.0~~	110.0	104.0	97.0	88.0	83.0	96.0	104.0	106.0	99.0
CYL.NO.3,4	~~106.0~~	124.0	117.0	110.0	103.0	99.0	109.0	117.0	120.0	114.0
CARB. BASE	~~107.0~~	102.0	95.0	87.0	77.0	74.0	87.0	95.0	102.0	95.0
NO.D.MOLES PER.MOLE F	33.820	48.844	40.059	34.212	29.970	29.981	34.499	40.097	48.651	38.983
NO.M.W./D.	1.1313	1.1295	1.1298	1.1287	1.1272	1.1275	1.1280	1.1300	1.1303	1.1341
TEST. NO.	100	101	102	103	104	105	106	107	108	109

TEST NO.	110	111	112	113	114	119	120	121	122	123
% METH.	20.00	30.00	30.00	20.00	10.00	.00	10.00	20.00	20.00	30.00
SPARK ADV. DEG. BTDC	34.0	34.0	34.0	34.0	34.0	51.5	51.5	51.5	50.0	51.5
MAN. VAC. INCH.HG.	9.40	9.20	8.00	9.10	9.80	16.00	15.70	15.40	15.40	14.90
TORQUE FT. LBS.	85.00	79.00	88.00	87.50	88.50	46.50	46.50	46.00	45.50	46.00
ENG. SPEED R.P.M.	1840.00	1760.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	1990.00	2000.00
EQ. RATIO FUEL/AIR	~~9.199~~	~~9.427~~	~~10.150~~	~~10.042~~	~~10.065~~	~~7.178~~	~~7.064~~	~~6.895~~	~~6.895~~	~~6.845~~
F/A STOICH	.0781	.0836	.0836	.0781	.0733	.0689	.0733	.0781	.0781	.0836
B.S.F.C. LBS/HP HR	.5867	.6316	.6010	.5589	.5193	.6564	.6868	.7226	.7342	.7675
COR B.H.P.	28.53	25.79	32.65	32.46	32.83	17,13	17.13	16.94	16.67	16.94
COR. BMEP. P.S.I.	61.90	58.92	65,63	65.26	66.00	34,42	34.42	34.05	33.68	34.05
VOL. EF. %	~~6.19~~	~~5.43~~	~~4.78~~	~~4.78~~	~~4.78~~	~~4.71~~	~~4.71~~	~~4.71~~	~~4.74~~	~~4.71~~
B.TH.E. %	25.81	25.61	26.92	27.10	27.39	20,41	20.71	20.96	20.63	21.08
% O2	3.50	4.50	4.15	3.30	2.50	1,10	2.35	3.50	3.45	4.55
% CO	.1895	.1895	.2017	.1895	.1736	.2448	.1697	.2017	.2017	.2059
% CO_2	12.60	11.80	12.00	12.60	12.20	14,50	13.60	12.80	12.80	12.00
% CH3OH	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~
% HCHO	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~
NO. PPM W.	2500.0	1450.0	1400.0	2350.0	3200.0	3250.0	3100.0	2050.0	1800.0	750.0
NO2 PPM W	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~
NOX PPM W	2500.0	1450.0	1400.0	2350.0	3200.0	3250.0	3100.0	2050.0	1800.0	750.0
HC PPM W	550.0	500.0	330.0	450.0	600.0	2050.0	1250.0	900.0	760.0	620.0
MASS O2 GRMS/HP HR	147.221	202.899	175.205	132.345	102.680	50.484	114.146	177.831	178.323	244.626
MASS CO GRMS/HP HR	6.973	7.474	7.452	6.648	6.238	9.832	7.212	8.968	9.123	9.685
MASS CO2 GRMS/HP HR	728.742	731.564	696.597	694.811	688.985	915.014	908.307	894.234	909.706	887.107
MASS NOX GRMS/HP HR	11.161	5.937	6.285	10.004	13.806	15.858	16.000	11.072	9.892	4.287
MASS HC GRMS/HP HR	1.134	1.105	.726	.885	1.196	4.621	2,981	2.246	1.930	1.637
EQ.R.CHM.	.848	.803	.818	.855	.882	.978	.905	.854	.855	.807
TEST NO.	110	111	112	113	114	119	120	121	122	123

PAGE 2

TEST NO.	110	111	112	113	114	119	120	121	122	123
DATE	5.23	5.23	5.23	5.23	5.23	6.10	6.10	6.10	6.10	6.10
HC PPM D	622.7	565.9	397.0	509.5	672.3	2324.8	1416.8	1020.5	861.9	703.1
NOX PPM D	2830.2	1641.1	1588.0	2660.7	3585.5	3685.6	3513.6	2324.5	2041.3	850.5
DRY B TEMP DEG.F.	84.0	84.0	84.0	84.0	84.0	88.0	88.0	88.0	88.0	88.0
WET B TEMP DEG.F.	72.0	72.0	72.0	72.0	72.0	79.0	79.0	79.0	79.0	79.0
BAR.PRESS. INCH. HG.	29.75	29.75	29.75	29.75	29.75	30.08	30.08	30.08	30.08	30.08
IN.COOL.T. DEG.F.	171.0	173.0	177.0	178.0	177.0	172.0	171.0	171.0	171.0	171.0
OUT.COOL.T. DEG.F.	187.0	188.0	192.0	193.0	193.0	187.0	185.0	184.0	184.0	184.0
EXH.PRESS. P.S.I.	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.30~~	~~.30~~	~~.32~~	~~.33~~	~~.32~~
AIR FLOW LBS/HR	~~23.74~~	~~23.74~~	~~23.74~~	~~23.74~~	~~23.74~~	~~23.51~~	~~23.51~~	~~23.51~~	~~23.51~~	~~23.51~~
FUEL FLOW LBS/HR	17.07	16.73	20.15	18.63	17.51	11.63	12.17	12.66	12.66	13.45
EXH. TEMP. CYL.NO. 1	1039.0	1019.0	1060.0	1075.0	1099.0	1315.0	1279.0	1254.0	1265.0	1244.0
CYL.NO. 2	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	959.0	939.0	923.0	927.0	903.0
CYL.NO. 3	941.0	930.0	982.0	982.0	996.0	1235.0	1202.0	1178.0	1192.0	1159.0
CYL.NO. 4	991.0	962.0	1013.0	1004.0	1035.0	1287.0	1254.0	1237.0	1246.0	1229.0
INT.MAN.T. CYL.NO.1,2	68.0	81.0	81.0	90.0	98.0	109.0	103.0	94.0	93.0	83.0
CYL.NO.3,4	104.0	94.0	88.0	100.0	111.0	124.0	120.0	111.0	111.0	101.0
CARB. BASE	82.0	73.0	73.0	82.0	94.0	102.0	97.0	86.0	86.0	76.0
NO.D.MOLES PER.MOLE F	33.499	29.075	28.611	33.528	43.439	46.737	38.847	32.855	32.894	28.530
NO.M.A./D.	1.1321	1.1318	1.1343	1.1322	1.1205	1.1340	1.1334	1.1339	1.1340	1.1340
TEST. NO.	110	111	112	113	114	119	120	121	122	123

TEST NO.	124	126	127	128	129	130	139	140	141	142
% METH.	30.00	.00	10.00	20.00	30.00	.00	.00	10.00	20.00	30.00
SPARK ADV. DEG. BTDC	48.5	48.0	48.0	48.0	47.0	48.0	45.0	45.0	45.0	45.0
MAN. VAC. INCH.HG.	14.70	17.60	17.50	17.30	17.20	17.55	19.20	18.80	18.35	17.80
TORQUE FT. LBS.	46.00	32.50	32.50	32.50	32.50	32.50	23.00	23.00	23.00	23.00
ENG. SPEED R.P.M.	2000.00	1520.00	1490.00	1490.00	1500.00	1500.00	1150.00	1150.00	1150.00	1150.00
EQ. RATIO FUEL/AIR	[illegible]	~~4.698~~	~~4.484~~	~~4.332~~	~~4.152~~	~~4.698~~	~~3.013~~	~~2.852~~	~~2.867~~	~~2.814~~
F/A STOICH	.0836	.0689	.0733	.0781	.0836	.0689	.0689	.0733	.0781	.0836
B.S.F.C. LBS/HP HR	.7675	.8107	.8336	.8645	.8807	.8215	.9754	.9815	1.0469	1.0970
COR B.H.P.	16.94	9.06	8.88	8.88	8.94	8.94	4.87	4.87	4.91	4.93
COR. BMEP. P.S.I.	34.05	23.96	23.96	23.96	23.96	23.96	17.04	17.04	17.18	17.24
VOL. EF. %	~~4.71~~	~~6.17~~	[illegible]	~~6.30~~	~~6.25~~	~~6.25~~	~~8.25~~	~~8.25~~	~~8.34~~	~~8.38~~
B.TH.E. %	21.08	16.52	17.06	17.52	18.37	16.31	13.73	14.49	14.47	14.75
% O2	4.55	1.10	1.60	2.60	4.60	.95	1.55	3.10	4.25	5.30
% CO	.2039	.4376	.1736	.1582	.1697	.6988	.1325	.1433	.1507	.1397
% CO2	12.00	14.00	14.30	13.60	12.10	14.60	14.00	12.90	12.10	11.40
% CH3OH	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~
% HCHO	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~
NO. PPM W.	750.0	2250.0	2450.0	1900.0	620.0	2350.0	1350.0	950.0	460.0	165.0
NO2 PPM W	~~.0~~	150.0	~~.0~~	50.0	150.0	200.0	100.0	100.0	100.0	85.0
NOX PPM W	750.0	2400.0	2450.0	1950.0	770.0	2550.0	1450.0	1050.0	560.0	250.0
HC PPM W	620.0	2100.0	1700.0	1300.0	1050.0	2250.0	2000.0	1800.0	1550.0	1550.0
MASS O2 GRMS/HP HR	244.626	61.132	89.468	148.922	281.187	52.541	110.276	226.007	329.947	426.822
MASS CO GRMS/HP HR	9.635	21.231	8.492	7.929	9.076	33.819	8.250	9.145	10.238	9.845
MASS CO2 GRMS/HP HR	887.107	1115.655	1099.475	1071.096	1017.011	1110.280	1369.558	1293.159	1291.647	1262.346
MASS NOX GRMS/HP HR	4.287	14.681	14.639	12.116	5.526	15.673	11.318	8.489	5.024	2.510
MASS HC GRMS/HP HR	1.637	5.743	4.693	3.681	3.154	6.133	6.956	6.399	5.866	6.087
EQ.R.CHM.	.807	.979	.945	.898	.909	.994	.950	.879	.826	.779
TEST NO.	124	126	127	128	129	130	139	140	141	142

PAGE 2

TEST NO.	124	126	127	128	129	130	139	140	141	142
DATE	6.10	6.11	6.11	6.11	6.11	6.11	6.16	6.16	6.16	6.16
HC PPM D	703.1	2386.1	1937.7	1483.9	1191.1	2560.1	2257.4	2026.3	1744.6	1745.2
NOX PPM D	850.5	2726.9	2792.5	2225.8	873.5	2901.4	1636.6	1182.0	630.3	281.5
DRY B TEMP DEG.F.	88.0	85.0	85.0	85.0	85.0	85.0	87.0	87.0	96.0	100.0
WET B TEMP DEG.F.	79.0	78.0	78.0	78.0	78.0	78.0	76.0	76.0	76.0	76.0
BAR.PRESS. INCH. HG.	30.08	30.12	30.12	30.12	30.12	30.12	30.03	30.03	30.03	30.03
IN.COOL.T. DEG.F.	171.0	176.0	176.0	176.0	176.0	177.0	166.0	170.0	168.0	169.0
OUT.COOL.T. DEG.F.	184.0	191.0	190.0	189.0	180.0	192.0	180.0	184.0	182.0	182.0
EXH.PRESS. P.S.I.	~~.00~~	~~.35~~	~~.35~~	~~.19~~	~~.30~~	~~.35~~	.05	.05	.00	.00
AIR FLOW LBS/HR	~~23.51~~	~~23.56~~	~~23.56~~	~~23.56~~	~~23.56~~	~~23.56~~	~~23.67~~	~~23.67~~	~~23.55~~	~~23.49~~
FUEL FLOW LBS/HR	10.45	7.03	7.69	7.97	8.18	7.63	4.91	4.95	5.27	5.53
EXH. TEMP. CYL.NO. 1	1252.0	1234.0	1221.0	1206.0	1167.0	1213.0	1095.0	1067.0	1070.0	1092.0
CYL.NO. 2	914.0	827.0	824.0	825.0	813.0	822.0	692.0	673.0	543.0	692.0
CYL.NO. 3	1171.0	1145.0	1124.0	1114.0	1095.0	1136.0	1010.0	972.0	995.0	989.0
CYL.NO. 4	1236.0	1171.0	1153.0	1133.0	1116.0	1166.0	1036.0	990.0	976.0	994.0
INT.MAN.T. CYL.NO.1,2	84.0	118.0	95.0	105.0	101.0	118.0	117.0	110.0	106.0	102.0
CYL.NO.3,4	102.0	129.0	124.0	117.0	114.0	129.0	127.0	120.0	117.0	11[illegible].0
CARB. BASE	76.0	109.0	103.0	94.0	92.0	108.0	104.0	98.0	94.0	91.0
NO.D.MOLES PER.MOLE F	28.530	45.823	36.844	30.958	28.271	45.002	48.752	40.798	34.649	29.899
NO.M.W./D.	1.1340	1.1362	1.1398	1.1415	1.1344	1.1378	1.1287	1.1257	1.1255	1.1259
TEST. NO.	124	126	127	128	129	130	139	140	141	142

TEST NO.	143	144	146	147	148	149	150	151	152	153
% METH.	20.00	.00	.00	10.00	20.00	30.00	30.00	20.00	10.00	.00
SPARK ADV. DEG. BTDC	45.0	45.0	47.5	47.5	47.5	47.5	45.0	45.0	45.0	45.0
MAN. VAC. INCH.HG.	18.25	19.10	17.70	17.60	17.00	16.60	17.70	18.10	18.60	19.00
TORQUE FT. LBS.	23.00	23.50	32.50	32.50	32.50	32.50	23.50	23.50	23.50	23.50
ENG. SPEED R.P.M.	1150.00	1150.00	1560.00	1560.00	1540.00	1560.00	1200.00	1200.00	1200.00	1200.00
EQ. RATIO FUEL/AIR	~~2.873~~	~~3.044~~	~~4.675~~	~~4.432~~	~~4.387~~	~~4.204~~	~~2.764~~	~~3.065~~	~~3.017~~	~~3.099~~
F/A STOICH	.0781	.0689	.0689	.0733	.0781	.0836	.0836	.0781	.0733	.0689
B.S.F.C. LBS/HP HR	1.0469	.9547	.7899	.7962	.8513	.8615	1.0184	1.0348	.9744	.9415
COR B.H.P.	4.93	5.06	9.34	9.34	9.22	9.34	5.19	5.19	5.19	5.19
COR. BMEP. P.S.I.	17.24	17.69	24.06	24.06	24.06	24.06	17.40	17.40	17.40	17.40
VOL. EF. %	~~6.58~~	~~4.43~~	~~6.08~~	~~6.08~~	~~6.16~~	~~6.08~~	~~7.90~~	~~7.90~~	~~7.90~~	~~7.90~~
B.TH.E. %	14.47	14.03	16.96	17.86	17.79	18.78	15.89	14.63	14.60	14.23
% O2	4.10	1.40	1.40	2.45	3.70	4.75	5.40	4.25	3.80	1.45
% CO	.1544	.1976	.1895	.1507	.1697	.1775	.1470	.1470	.1397	.1507
% CO2	12.10	14.00	14.00	13.30	12.40	11.80	11.30	10.10	12.90	13.60
% CH3OH	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~
% HCHO	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~
NO. PPM W.	530.0	1500.0	2600.0	2300.0	1350.0	720.0	165.0	575.0	1300.0	1700.0
NO2 PPM W	100.0	150.0	200.0	200.0	150.0	70.0	105.0	110.0	100.0	100.0
NOX PPM W	630.0	1650.0	2800.0	2500.0	1500.0	790.0	270.0	685.0	1400.0	1800.0
HC PPM W	1400.0	2250.0	1950.0	1550.0	1180.0	1100.0	1450.0	1400.0	1650.0	2300.0
MASS O2 GRMS/HP HR	318.639	96.856	80.368	140.851	228.476	290.788	407.301	389.590	275.452	102.051
MASS CO GRMS/HP HR	10.503	11.901	9.516	7.582	9.168	9.507	9.703	11.792	8.862	9.281
MASS CO2 GRMS/HP HR	1293.013	1331.763	1105.063	1051.356	1052.843	993.269	1171.933	1273.043	1285.744	1316.108
MASS NOX GRMS/HP HR	5.605	12.606	17.663	15.876	10.328	5.371	2.593	7.061	11.120	13.754
MASS HC GRMS/HP HR	5.305	7.611	5.475	4.361	3.564	3.299	5.329	6.141	5.832	7.886
EQ.R.CHM.	.830	.901	.955	.903	.845	.801	.774	.797	.650	.956
TEST NO.	143	144	146	147	148	149	150	151	152	153

PAGE 2

TEST NO.	143	144	146	147	148	149	150	151	152	153
DATE	6.16	6.16	6.17	6.17	6.17	6.17	6.17	6.17	6.17	6.17
HC PPM D	1576.0	2539.9	2201.8	1751.5	1332.4	1244.2	1631.2	1546.8	1857.7	2586.9
NOX PPM D	709.2	1862.6	3161.6	2825.0	1693.8	893.6	303.7	756.8	1576.2	2024.5
DRY B TEMP DEG.F.	100.0	105.0	87.0	87.0	87.0	87.0	87.0	87.0	87.0	87.0
WET B TEMP DEG.F.	76.0	76.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0
BAR.PRESS. INCH. HG.	30.03	30.03	30.05	30.05	30.05	30.05	30.05	30.05	30.05	30.05
IN.COOL.T. DEG.F.	167.0	169.0	170.0	170.0	167.0	167.0	167.0	165.0	172.0	171.0
OUT.COOL.T. DEG.F.	182.0	184.0	185.0	184.0	181.0	180.0	181.0	179.0	186.0	187.0
EXH.PRESS. P.S.I.	.00	.00	.21	.20	.26	.17	.02	.06	.04	.02
AIR FLOW LBS/HR	~~[illegible]~~	~~23.42~~	~~23.68~~	~~23.68~~	~~23.68~~	~~23.68~~	~~23.68~~	~~23.68~~	~~23.68~~	~~23.68~~
FUEL FLOW LBS/HR	5.27	4.91	7.63	7.69	8.12	8.32	5.47	5.56	5.23	5.06
EXH. TEMP. CYL.NO. 1	1080.0	1107.0	1211.0	1180.0	1165.0	1156.0	1077.0	1075.0	1086.0	1102.0
CYL.NO. 2	683.0	713.0	811.0	801.0	789.0	792.0	705.0	697.0	697.0	692.0
CYL.NO. 3	987.0	1008.0	1138.0	1114.0	1107.0	1101.0	1001.0	1000.0	1003.0	1011.0
CYL.NO. 4	984.0	1018.0	1139.0	1105.0	1090.0	1182.0	1003.0	990.0	1008.0	1019.0
INT.MAN.T. CYL.NO.1,2	113.0	131.0	113.0	112.0	107.0	100.0	99.0	103.0	112.0	118.0
CYL.NO.3,4	130.0	140.0	126.0	124.0	120.0	115.0	116.0	120.0	128.0	134.0
CARB. BASE	103.0	117.0	106.0	105.0	101.0	94.0	86.0	96.0	103.0	110.0
NO.D.MOLES	34.636	48.438	48.579	39.661	33.891	28.941	30.167	41.389	40.861	49.966
PER.MOLE F NO.M.W./C.	1.1257	1.1208	1.1291	1.1300	1.1292	1.1311	1.1250	1.1049	1.1259	1.1247
TEST. NO.	143	144	146	147	148	149	150	151	152	153

TEST NO.	157	163	207	240	242	256	271	288	289	290
% METH.	.00	.00	.00	.00	.00	.00	.00	20.00	30.00	30.00
SPARK ADV. DEG. BTDC	51.0	39.0	51.0	51.0	51.0	51.0	51.0	51.0	51.0	51.0
MAN. VAC. INCH.HG.	16.05	16.00	16.00	16.00	16.00	16.00	16.00	16.07	16.00	16.00
TORQUE FT. LBS.	32.50	48.00	47.00	47.00	46.50	47.00	48.00	49.00	49.00	49.50
ENG. SPEED R.P.M.	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00
EQ. RATIO FUEL/AIR	1.205	1.166	.968	.993	.989	.993	.984	1.182	1.104	1.065
F/A STOICH	.0689	.0689	.0689	.0689	.0689	.0689	.0689	.0781	.0836	.0836
B.S.F.C. LBS/HP HR	.8122	.6515	.6414	.6574	.6564	.6574	.6358	.8458	.8503	.8115
COR B.H.P.	11.91	17.50	17.30	17.41	17.24	17.33	17.67	18.14	18.05	18.24
COR. BMEP. P.S.I.	23.95	35.19	34.78	35.00	34.66	34.84	35.51	36.45	36.28	36.67
VOL. EF. %	24.06	29.16	34.39	34.81	34.61	34.54	34.34	34.50	34.52	34.55
B.TH.E. %	16.49	20.56	20.88	20.38	20.41	20.38	21.07	17.91	19.02	19.93
% O2	4.65	1.40	1.35	1.35	1.35	1.35	1.35	.50	.57	.62
% CO	.1854	.5527	.6087	.7797	.4376	.6988	.5944	3.5130	3.2439	2.2120
% CO2	11.80	14.10	13.80	13.80	13.70	13.70	13.90	11.80	12.80	13.30
% CH3OH	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~
% HCHO	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~
NO. PPM W.	1300.0	2250.0	3000.0	2950.0	3450.0	3800.0	.0	1175.0	2200.0	2800.0
NO2 PPM W	200.0	150.0	150.0	250.0	300.0	100.0	.0	75.0	100.0	150.0
NOX PPM W	1500.0	2400.0	3150.0	3200.0	3750.0	3900.0	.0	1250.0	2300.0	2950.0
HC PPM W	1000.0	1550.0	1800.0	1600.0	1550.0	2050.0	.0	2800.0	2650.0	2450.0
MASS O2 GRMS/HP HR	326.974	64.414	62.058	62.961	64.835	63.522	62.021	24.924	25.488	27.389
MASS CO GRMS/HP HR	11.409	22.249	24.484	31.818	18.390	28.772	23.894	153.227	126.922	85.502
MASS CO2 GRMS/HP HR	1140.893	892.019	872.259	884.954	904.685	886.369	878.051	808.789	786.993	807.856
MASS NOX GRMS/HP HR	11.755	12.120	15.734	16.494	19.867	19.701	.000	6.903	11.484	14.585
MASS HC GRMS/HP HR	3.380	3.500	4.051	3.658	3.639	4.720	.000	6.922	5.975	5.448
EQ.R.CHM.	.801	.903	.907	.969	.957	.970	.956	1.116	1.095	1.056
TEST NO.	157	163	207	240	242	256	271	288	289	290

PAGE 2

TEST NO.	157	163	207	240	242	256	271	288	289	290
DATE	6.20	6.23	6.27	6.30	6.30	7.10	7.03	7.03	7.03	7.03
HC PPM D	1109.8	1756.2	2034.6	1810.7	1749.2	2315.9	.0	3206.2	3084.8	2847.5
NOX PPM D	1664.7	2719.2	3560.5	3621.4	4232.0	4405.8	.0	1431.3	2677.4	3428.6
DRY B TEMP DEG.F.	83.0	78.0	84.5	92.0	93.0	89.0	88.0	90.5	89.0	89.5
WET B TEMP DEG.F.	76.0	73.0	76.5	71.5	79.5	76.0	78.0	77.5	77.0	77.0
BAR.PRESS. INCH. HG.	30.08	30.10	30.00	30.01	30.01	30.07	30.10	30.00	30.10	30.10
IN.COOL.T. DEG.F.	165.0	171.0	170.0	173.0	170.0	174.0	173.0	173.0	174.0	173.0
OUT.COOL.T. DEG.F.	178.0	186.0	185.0	189.0	186.0	189.0	184.0	189.0	190.0	189.0
EXH.PRESS. P.S.I.	.12	.16	.19	.21	.22	.10	.12	.19	.17	.17
AIR FLOW LBS/HR	121.12	148.28	172.16	171.98	170.67	171.93	171.40	170.88	172.01	171.96
FUEL FLOW LBS/HR	10.06	11.91	11.48	11.77	11.63	11.77	11.63	15.79	15.87	15.30
EXH. TEMP.										
CYL.NO. 1	1295.0	1326.0	1261.0	1269.0	1276.0	1268.0	1262.0	1227.0	1244.0	1259.0
CYL.NO. 2	843.0	994.0	848.0	822.0	821.0	815.0	810.0	766.0	781.0	766.0
CYL.NO. 3	1177.0	1241.0	1201.0	1192.0	1242.0	1203.0	1204.0	1110.0	1134.0	1151.0
CYL.NO. 4	1170.0	1275.0	1245.0	1246.0	1239.0	1248.0	1246.0	1172.0	1200.0	1214.0
INT.MAN.T.										
CYL.NO.1+2	100.0	100.0	98.0	101.0	101.0	99.0	99.0	77.0	69.0	71.0
CYL.NO.3+4	113.0	115.0	112.0	114.0	114.0	113.0	112.0	85.0	80.0	80.0
CARB. BASE	93.0	92.0	90.0	93.0	94.0	91.0	91.0	63.0	57.0	58.0
NO.D.MOLES PER.MOLE F	57.868	47.207	47.905	47.423	48.908	47.845	48.294	27.538	21.418	22.172
NO.M.W./D.	1.1098	1.1330	1.1303	1.1317	1.1285	1.1297	1.1333	1.1451	1.1641	1.1622
TEST. NO.	157	163	207	240	242	256	271	288	289	290

TEST NO.	291	292	293	294	295	296	297	298	299	300
% METH.	.00	.00	.00	.00	.00	.00	.00	.00	.00	20.00
SPARK ADV. DEG. BTDC	51.0	37.5	37.5	38.0	40.0	42.5	46.0	50.0	54.5	37.5
MAN. VAC. INCH.HG.	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
TORQUE FT. LBS.	47.00	51.50	51.30	50.75	49.75	49.00	46.70	43.40	38.30	51.50
ENG. SPEED R.P.M.	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00
EQ. RATIO FUEL/AIR	.972	1.174	1.133	1.089	1.041	.970	.949	.902	.819	1.394
F/A STOICH	.0689	.0689	.0689	.0689	.0689	.0689	.0689	.0689	.0689	.0781
B.S.F.C. LBS/HP HR	.6494	.7309	.6973	.6753	.6587	.6229	.6375	.6600	.6892	.9713
COR B.H.P.	17.25	18.90	18.84	18.63	18.26	18.00	17.15	15.94	14.07	18.92
COR. BMEP. P.S.I.	34.07	37.99	37.87	37.45	36.71	36.18	34.48	32.04	28.29	38.04
VOL. EF. %	34.53	35.27	34.79	34.66	34.66	34.68	34.57	35.00	35.55	34.92
B.TH.E. %	20.03	18.33	19.21	19.84	20.34	21.50	21.01	20.29	19.43	15.59
% O2	1.35	.37	.45	.58	.80	1.22	2.00	2.95	4.55	.45
% CO	.5527	5.2754	3.4585	2.0791	.9770	.7067	.2724	.1814	.1830	4.8106
% CO2	13.90	11.80	12.90	13.50	13.90	14.00	13.56	12.96	11.84	11.90
% CH3OH	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~
% HCHO	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~
NO. PPM W.	4650.0	940.0	1600.0	2200.0	3000.0	3400.0	3100.0	2700.0	1350.0	850.0
NO2 PPM W	250.0	10.0	100.0	100.0	100.0	200.0	200.0	150.0	200.0	50.0
NOX PPM W	4900.0	950.0	1700.0	2300.0	3100.0	3600.0	3300.0	2850.0	1550.0	900.0
HC PPM W	2050.0	2900.0	2700.0	2550.0	2300.0	2000.0	1700.0	1450.0	1700.0	2800.0
MASS O2 GRMS/HP HR	62.521	16.272	19.716	25.847	36.456	53.291	95.211	153.275	268.930	23.643
MASS CO GRMS/HP HR	22.395	203.007	132.588	81.071	38.957	27.010	11.348	8.249	9.466	221.153
MASS CO2 GRMS/HP HR	885.129	713.557	777.147	827.207	870.952	840.863	887.605	925.884	962.237	859.672
MASS NOX GRMS/HP HR	24.706	4.486	8.203	11.171	15.265	17.192	17.119	15.985	10.184	5.270
MASS HC GRMS/HP HR	4.649	6.291	5.936	5.593	5.144	4.286	3.947	3.655	4.828	7.356
EQ.R.CHM.	.903	1.109	1.103	1.054	1.007	.976	.926	.879	.812	1.156
TEST NO.	291	292	93	294	295	296	297	298	299	300

PAGE 2

TEST NO.	291	292	293	294	295	296	297	298	299	300
DATE	7.04	7.04	7.04	7.04	7.04	7.04	7.04	7.04	7.04	7.04
HC PPM D	2317.7	3302.9	3075.4	2897.5	2606.1	2265.2	1914.1	1624.1	1885.9	3232.7
NOX PPM D	5539.8	1082.0	1936.4	2613.4	3512.6	4077.3	3715.6	3192.1	1719.5	1039.1
DRY B TEMP DEG.F.	84.0	84.0	85.0	84.5	84.5	85.0	85.0	85.0	85.5	85.5
WET B TEMP DEG.F.	74.5	74.0	74.5	74.5	74.5	74.5	75.0	75.0	75.5	75.5
BAR.PRESS. INCH. HG.	30.08	30.08	30.08	30.08	30.08	30.08	30.08	30.08	30.08	30.08
IN.COOL.T. DEG.F.	172.0	170.0	173.0	171.0	171.0	170.0	173.0	171.0	169.0	170.0
OUT.COOL.T. DEG.F.	188.0	186.0	188.0	186.0	186.0	186.0	187.0	185.0	182.0	185.0
EXH.PRESS. P.S.I.	.11	.15	.15	.17	.17	.17	.10	.16	.16	.19
AIR FLOW LBS/HR	173.51	177.24	174.48	174.00	174.00	173.95	173.41	175.55	178.16	174.97
FUEL FLOW LBS/HR	11.63	14.34	13.63	13.06	12.48	11.63	11.34	10.91	10.06	19.06
EXH. TEMP. CYL.NO. 1	1250.0	1244.0	1271.0	1288.0	1283.0	1278.0	1238.0	1211.0	1178.0	1253.0
CYL.NO. 2	796.0	787.0	763.0	821.0	831.0	813.0	787.0	769.0	751.0	775.0
CYL.NO. 3	1201.0	1142.0	1166.0	1189.0	1204.0	1210.0	1199.0	1170.0	1141.0	1125.0
CYL.NO. 4	1243.0	1206.0	1227.0	1249.0	1270.0	1267.0	1256.0	1230.0	1201.0	1196.0
INT.MAN.T. CYL.NO.1,2	94.0	89.0	92.0	93.0	94.0	95.0	96.0	96.0	98.0	73.0
CYL.NO.3,4	106.0	101.0	104.0	106.0	107.0	108.0	106.0	106.0	107.0	81.0
CARB. BASE	85.0	80.0	83.0	84.0	86.0	87.0	87.0	87.0	88.0	58.0
NO.D.MOLES PER.MOLE F	47.670	40.217	42.002	44.112	46.242	46.875	49.915	52.616	57.322	25.274
NO.M.W./D.	1.1306	1.1389	1.1390	1.1363	1.1331	1.1326	1.1259	1.1200	1.1094	1.1545
TEST. NO.	291	292	293	294	295	296	297	298	299	300

TEST NO.	301	302	303	304	305	306	307	308	309	310
% METH.	20.00	20.00	20.00	20.00	20.00	20.00	20.00	.00	.00	20.00
SPARK ADV. DEG. BTDC	37.5	38.0	40.0	42.5	46.0	50.0	54.5	51.0	42.5	42.5
MAN. VAC. INCH.HG.	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
TORQUE FT. LBS.	51.80	51.50	50.70	49.80	47.80	44.75	39.90	47.00	48.00	49.00
ENG. SPEED R.P.M.	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00
EQ. RATIO FUEL/AIR	1.130	1.092	1.029	1.007	.933	.888	.811	.993	.993	.979
F/A STOICH	.0781	.0781	.0781	.0781	.0781	.0781	.0781	.0689	.0689	.0781
B.S.F.C. LBS/HP HR	.7764	.7540	.7218	.7198	.7031	.7177	.7489	.6653	.6515	.7240
COR B.H.P.	19.02	18.93	18.64	18.35	17.62	16.48	14.69	17.23	17.60	18.00
COR. BMEP. P.S.I.	38.24	38.06	37.47	36.88	35.42	33.13	29.52	34.64	35.38	36.18
VOL. EF. %	34.68	34.62	34.62	34.83	35.28	35.35	35.96	34.58	34.58	35.20
B.TH.E. %	19.45	20.08	20.98	21.04	21.54	21.10	20.22	20.13	20.56	20.92
% O2	.50	.60	.90	1.15	1.95	3.05	4.55	1.35	1.25	1.25
% CO	3.6452	2.3028	1.0602	.8396	.3317	.1814	.1854	.6232	.6306	.7467
% CO2	12.46	13.30	13.80	13.90	13.60	12.90	11.90	13.70	13.50	13.80
% CH3OH	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~
% HCHO	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~
NO. PPM W.	1125.0	1600.0	2200.0	2700.0	2650.0	2550.0	1550.0	3300.0	2400.0	2350.0
NO2 PPM W	75.0	100.0	200.0	200.0	250.0	100.0	150.0	250.0	300.0	250.0
NOX PPM W	1200.0	1700.0	2400.0	2900.0	2900.0	2650.0	1700.0	3550.0	2700.0	2600.0
HC PPM W	2600.0	2350.0	2050.0	1850.0	1325.0	1225.0	1125.0	1950.0	1750.0	1650.0
MASS O2 GRMS/HP HR	21.862	26.261	39.651	51.015	89.711	152.575	257.108	64.677	59.521	56.587
MASS CO GRMS/HP HR	130.458	88.193	40.871	32.588	13.354	7.942	9.168	26.126	26.272	29.578
MASS CO2 GRMS/HP HR	749.090	800.416	835.965	847.841	860.304	887.313	924.601	902.490	883.887	858.998
MASS NOX GRMS/HP HR	5.861	8.295	11.901	14.369	14.950	14.382	10.600	18.683	14.398	13.313
MASS HC GRMS/HP HR	5.678	5.156	4.497	4.085	3.017	3.211	3.095	4.570	4.070	3.713
EQ.R.CHM.	1.113	1.061	1.005	.984	.928	.874	.808	.967	.972	.976
TEST NO.	301	302	303	304	305	306	307	308	309	310

PAGE 2

TEST NO.	301	302	303	304	305	306	307	308	309	310
DATE	7.04	7.04	7.04	7.04	7.04	7.04	7.04	7.08	7.08	7.08
* HC PPM D	2998.1	2709.4	2356.5	2125.9	1514.1	1389.7	1264.7	2202.1	1973.5	1893.5
NOX PPM D	1363.7	1960.0	2758.8	3332.5	3314.0	3006.2	1911.1	4009.0	3044.9	2983.8
DRY B TEMP DEG.F.	85.0	86.0	86.0	88.5	89.0	88.0	87.5	82.5	82.5	84.5
WET B TEMP DEG.F.	75.0	75.0	75.0	76.5	77.0	76.5	76.5	74.0	74.0	74.5
BAR.PRESS. INCH. HG.	30.08	30.08	30.08	30.08	30.08	30.08	30.08	30.06	30.06	30.06
IN.COOL.T. DEG.F.	170.0	169.0	169.0	167.0	166.0	163.0	161.0	175.0	173.0	175.0
OUT.COOL.T. DEG.F.	185.0	185.0	185.0	182.0	181.0	177.0	174.0	191.0	189.0	190.0
EXH.PRESS. P.S.I.	.20	.18	.19	.19	.19	.16	.18	.19	.12	.15
AIR FLOW LBS/HR	173.95	173.32	173.32	173.60	175.68	176.31	179.54	174.13	174.13	176.60
FUEL FLOW LBS/HR	15.36	14.79	13.94	13.66	12.80	12.24	11.38	11.91	11.91	13.51
EXH. TEMP. CYL.NO. 1	1265.0	1281.0	1277.0	1261.0	1224.0	1197.0	1169.0	~~0~~	~~0~~	~~0~~
CYL.NO. 2	786.0	805.0	813.0	802.0	784.0	762.0	741.0	781.0	800.0	801.0
CYL.NO. 3	1141.0	1167.0	1183.0	1184.0	1195.0	1174.0	1128.0	~~0~~	~~0~~	~~0~~
CYL.NO. 4	1210.0	1231.0	1256.0	1256.0	1245.0	1220.0	1188.0	~~0~~	~~0~~	~~0~~
INT.MAN.T. CYL.NO.1,2	75.0	76.0	79.0	80.0	92.0	81.0	82.0	95.0	96.0	82.0
CYL.NO.3,4	83.0	84.0	88.0	90.0	92.0	92.0	92.0	197.0	108.0	92.0
CARB. BASE	59.0	61.0	63.0	65.0	67.0	67.0	68.0	86.0	86.0	67.0
NO.D.MOLES PER.MOLE F	26.243	27.121	28.319	28.793	30.570	32.565	35.254	48.132	48.856	29.215
NO.M.W./D.	1.1531	1.1530	1.1495	1.1491	1.1427	1.1344	1.1242	1.1293	1.1277	1.1476
TEST. NO.	301	302	303	304	305	306	307	308	309	310

TEST NO.	324	325	326	327	328	329	330	331	332	333
% METH.	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
SPARK ADV. DEG. BTDC	43.0	37.5	37.5	38.0	40.0	42.5	46.0	50.0	53.0	54.0
MAN. VAC. INCH.HG.	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
TORQUE FT. LBS.	49.00	50.05	51.50	51.00	49.75	49.40	47.40	44.50	41.15	39.50
ENG. SPEED R.P.M.	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00
EQ. RATIO FULL/AIR	.982	1.191	1.140	1.087	1.042	.990	.943	.893	.839	.816
F/A STOICH	.0689	.0689	.0689	.0689	.0689	.0689	.0689	.0689	.0689	.0689
B.S.F.C. LBS/HP HR	.6229	.7358	.6945	.6646	.6512	.6254	.6202	.6353	.6506	.6588
COR B.H.P.	17.99	18.60	18.91	18.72	18.26	18.12	17.40	16.36	15.15	14.54
COR. BMEP. P.S.I.	36.17	37.38	38.01	37.63	36.70	36.43	34.99	32.89	30.46	29.23
VOL. EF. %	34.22	34.44	34.54	34.31	34.20	34.28	34.33	34.93	35.31	35.31
B.TH.E. %	21.50	18.20	19.29	20.15	20.57	21.42	21.60	21.08	20.59	20.33
% O2	1.35	.40	.40	.55	.75	1.25	2.05	2.95	3.80	4.20
% CO	.4376	5.4856	3.8474	2.2120	1.0432	.4262	.2404	.1736	.1697	.1361
% CO2	13.90	11.64	13.50	13.20	13.70	13.90	13.50	12.96	12.30	12.10
% CH3OH	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~
% HCHO	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~
NO. PPM W.	2250.0	520.0	795.0	1250.0	1800.0	2275.0	2300.0	2100.0	1600.0	1375.0
NO2 PPM W	200.0	40.0	105.0	100.0	125.0	75.0	200.0	100.0	100.0	125.0
NOX PPM W	2450.0	560.0	900.0	1350.0	1925.0	2350.0	2500.0	2200.0	1700.0	1500.0
HC PPM W	1400.0	2650.0	2400.0	2250.0	2000.0	1750.0	1450.0	1250.0	1100.0	1050.0
MASS O2 GRMS/HP HR	60.654	17.687	16.510	24.433	34.166	56.370	95.761	147.866	205.606	234.569
MASS CO GRMS/HP HR	17.204	212.235	134.948	85.984	41.581	16.816	9.825	7.612	8.033	6.651
MASS CO2 GRMS/HP HR	858.706	707.606	766.134	806.296	858.125	861.891	867.101	893.211	915.081	929.202
MASS NOX GRMS/HP HR	12.172	2.744	4.244	6.632	9.629	11.418	12.847	11.862	9.910	9.123
MASS HC GRMS/HP HR	3.519	5.706	4.423	4.912	4.467	3.863	3.302	3.040	2.872	2.825
EQ.R.CHM.	.961	1.174	1.111	1.059	1.011	.967	.922	.879	.839	.820
TEST NO.	324	325	326	327	328	329	330	331	332	333

PAGE 2

TEST NO.	324	325	326	327	328	329	330	331	332	333
DATE	7.21	7.21	7.21	7.21	7.21	7.21	7.21	7.21	7.21	7.21
HC PPM D	1808.5	3017.9	2753.6	2553.0	2264.1	1977.6	1631.9	1400.3	1225.7	1167.8
NOX PPM D	2709.3	657.7	1032.6	1531.8	2179.2	2655.7	2813.6	2464.5	1894.2	1668.3
DRY B TEMP DEG.F.	84.0	84.0	84.0	83.5	83.5	83.0	84.0	85.5	87.0	87.0
WET B TEMP DEG.F.	74.5	74.5	74.5	74.5	74.0	74.5	74.5	76.0	76.5	76.5
BAR.PRESS. INCH. HG.	30.06	30.06	30.06	30.06	30.06	30.06	30.06	30.06	30.06	30.06
IN.COOL.T. DEG.F.	167.3	166.4	167.3	168.2	168.7	167.8	166.4	164.6	164.2	163.7
OUT.COOL.T. DEG.F.	183.5	182.6	183.0	184.4	184.8	183.9	182.6	179.4	178.1	178.1
EXH.PRESS. P.S.I.	.20	.20	.20	.20	.20	.21	.21	.22	.20	.20
AIR FLOW LBS/HR	171.65	172.92	173.45	172.43	171.90	172.48	172.38	174.91	176.35	176.35
FUEL FLOW LBS/HR	11.63	14.20	13.63	12.91	12.34	11.77	11.20	10.77	10.20	9.91
EXH. TEMP. CYL.NO. 1	1092.9	1058.0	1097.2	1112.1	1281.9	1098.1	1076.7	1053.3	1048.1	1048.1
CYL.NO. 2	761.3	747.0	767.2	800.1	803.5	780.0	755.1	735.8	731.9	727.2
CYL.NO. 3	1224.5	1057.1	1177.5	1195.4	1077.1	1224.1	1212.5	1186.9	1168.9	1156.5
CYL.NO. 4	1259.6	1193.3	1221.1	1246.3	1260.0	1261.7	1247.6	1228.8	1207.4	1195.0
INT.MAN.T. CYL.NO.1,2	88.7	83.7	85.1	86.9	88.3	89.6	90.1	91.9	92.8	93.7
CYL.NO.3,4	102.3	96.9	97.8	99.6	101.4	102.8	103.7	103.7	104.6	104.6
CARB. BASE	80.1	74.2	75.5	77.4	29.0	29.0	29.0	29.0	29.0	85.1
NO.D.MOLES PER.MOLE F	48.214	40.167	39.721	44.679	46.761	48.196	50.347	52.736	55.590	56.667
NO.M.W./D.	1.1303	1.1369	1.1473	1.1347	1.1320	1.1301	1.1255	1.1202	1.1142	1.1122
TEST. NO.	324	325	326	327	328	329	330	331	332	333

TEST NO.	334	335	336	337	338	339	340	341	342	343
% METH.	.00	.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
SPARK ADV. DEG. BTDC	54.5	56.0	36.5	37.5	38.0	40.0	42.5	46.0	50.0	54.5
MAN. VAC. INCH.HG.	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
TORQUE FT. LBS.	38.00	35.50	51.90	52.50	52.00	51.50	50.45	48.00	45.00	39.50
ENG. SPEED R.P.M.	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00
EQ. RATIO FUEL/AIR	.820	.806	1.208	1.129	1.081	1.023	.986	.940	.882	.807
F/A STOICH	.0689	.0689	.0781	.0781	.0781	.0781	.0781	.0781	.0781	.0781
B.S.F.C. LBS/HP HR	.6947	.7330	.8129	.7610	.7324	.7033	.6884	.6924	.6972	.7376
COR B.H.P.	13.98	13.06	19.13	19.34	19.17	18.96	18.55	17.63	16.53	14.51
COR. BMEP. P.S.I.	28.11	26.26	38.45	38.87	38.54	38.12	37.29	35.44	33.23	29.17
VOL. EF. %	35.61	35.72	34.15	34.59	34.49	34.57	34.29	34.35	34.56	35.10
B.TH.E. %	19.28	18.27	18.63	19.90	20.68	21.53	22.00	21.87	21.72	20.53
% O2	4.60	4.95	.40	.50	.60	.80	1.25	2.10	3.05	4.55
% CO	.1814	.1895	5.2754	3.4585	2.3489	.4908	.3793	.2228	.1697	.1736
% CO2	11.64	11.60	11.76	12.70	13.20	13.70	13.80	13.44	12.76	11.70
% CH3OH	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~
% HCHO	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~
NO. PPM W.	1150.0	1050.0	490.0	920.0	1275.0	1700.0	2150.0	2300.0	2100.0	1100.0
NO2 PPM W	100.0	150.0	30.0	40.0	75.0	100.0	100.0	100.0	150.0	150.0
NOX PPM W	1250.0	1100.0	520.0	960.0	1350.0	1800.0	2250.0	2400.0	2250.0	1250.0
HC PPM W	1025.0	1100.0	2400.0	2150.0	2050.0	1800.0	1550.0	1200.0	1050.0	950.0
MASS O2 GRMS/HP HR	275.757	319.010	17.305	21.368	25.652	36.012	55.227	97.096	150.155	258.127
MASS CO GRMS/HP HR	9.517	10.683	199.701	129.329	87.870	19.330	14.663	9.015	7.309	8.616
MASS CO2 GRMS/HP HR	975.959	1027.922	699.558	746.291	775.979	847.961	838.347	854.445	863.760	912.664
MASS NOX GRMS/HP HR	8.132	8.255	2.514	4.541	6.421	8.951	10.923	12.127	12.185	7.938
MASS HC GRMS/HP HR	2.954	3.402	5.200	4.596	4.375	4.016	3.396	2.741	2.537	2.620
EQ.R.CHM.	.804	.790	1.170	1.102	1.061	.992	.964	.918	.871	.804
TEST NO.	334	335	336	337	338	339	340	341	342	343

PAGE 2

TEST NO.	334	335	336	337	338	339	340	341	342	343
DATE	7.21	7.21	7.21	7.21	7.21	7.21	7.21	7.21	7.21	7.21
HC PPM D	1137.9	1218.7	2775.2	2482.9	2362.7	2060.1	1774.7	1368.5	1189.7	1066.1
NOX PPM D	1367.7	1218.7	601.3	1108.6	1555.9	2060.1	2576.1	2736.9	2549.4	1402.7
DRY B TEMP DEG.F.	86.5	86.5	88.0	87.5	88.5	87.0	85.5	84.5	84.5	84.5
WET B TEMP DEG.F.	76.0	76.0	77.5	77.0	77.5	76.0	75.0	74.0	74.5	74.5
BAR.PRESS. INCH. HG.	30.06	30.06	30.06	30.06	30.06	30.06	30.06	30.06	30.06	30.06
IN.COOL.T. DEG.F.	164.6	164.2	171.8	171.3	171.8	171.8	171.8	169.1	166.4	164.2
OUT.COOL.T. DEG.F.	178.5	178.1	187.5	187.5	187.5	188.4	188.0	184.8	182.1	178.1
EXH.PRESS. P.S.I.	.20	.20	.21	.20	.22	.23	.23	.23	.22	.20
AIR FLOW LBS/HR	176.00	178.53	170.23	172.58	171.77	172.63	171.70	172.33	173.40	176.07
FUEL FLOW LBS/HR	10.06	9.91	16.07	15.22	14.51	13.80	13.23	12.66	11.95	11.10
EXH. TEMP. CYL.NO. 1	1041.7	1048.1	1041.7	1077.6	1087.0	1084.4	1058.0	1033.2	1007.6	998.7
CYL.NO. 2	731.9	723.4	744.0	766.3	781.7	802.2	794.1	759.8	738.4	726.4
CYL.NO. 3	1151.8	1148.4	1136.9	1166.4	1177.9	1203.1	1218.1	1215.5	1187.7	1137.3
CYL.NO. 4	1197.6	1261.0	116[illegible].5	1211.7	1235.2	1255.3	1265.6	1241.6	1213.8	1184.7
INT.MAN.T. CYL.NO.1,2	93.7	94.2	68.3	70.1	72.4	74.2	75.1	75.5	76.9	78.7
CYL.NO.3,4	105.0	104.6	78.7	79.6	81.9	85.1	86.9	86.9	89.2	90.1
CARB. BASE	65.1	85.1	54.6	55.5	57.3	58.7	59.6	59.6	61.9	63.7
NO.D.MOLES PER.MOLE F	57.663	58.768	24.867	26.240	27.274	29.904	29.987	31.198	32.993	35.936
NO.M.W./D.	1.1161	1.1079	1.1563	1.1548	1.1526	1.1445	1.1449	1.1404	1.1331	1.1222
TEST. NO.	334	335	336	337	338	339	340	341	342	343

TEST NO.	344	345	346	347	348	349	350	351	352	353
% METH.	20.00	20.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00
SPARK ADV. DEG. BTDC	53.0	52.0	38.0	38.0	40.0	42.5	46.0	50.0	52.0	53.0
MAN. VAC. INCH.HG.	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
TORQUE FT. LBS.	40.50	42.50	52.90	52.50	52.00	51.00	48.50	45.50	43.50	41.50
ENG. SPEED R.P.M.	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00
EQ. RATIO FUEL/AIR	.828	.858	1.092	1.046	.976	.944	.898	.883	.854	.835
F/A STOICH	.0781	.0781	.0836	.0836	.0836	.0836	.0836	.0836	.0836	.0836
B.S.F.C. LBS/HP HR	.7378	.7119	.7606	.7509	.7077	.6996	.7048	.7431	.7514	.7696
COR B.H.P.	14.68	15.62	19.44	19.29	19.10	18.74	17.82	16.71	15.99	15.25
COR. BMEP. P.S.I.	29.92	31.40	39.08	38.77	38.40	37.68	35.81	33.60	32.14	30.66
VOL. EF. %	35.12	35.12	34.37	34.24	34.24	34.37	34.56	34.78	34.80	34.76
B.TH.E. %	20.53	21.27	20.72	21.54	22.86	23.12	22.95	21.77	21.53	21.02
% O2	4.20	3.60	.50	.55	.85	1.20	2.00	3.00	3.75	4.20
% CO	.1775	.1775	3.7908	2.3028	.9244	.6988	.2404	.1854	.1775	.1775
% CO2	~~.05~~	12.16	12.50	13.26	13.70	13.86	13.46	12.80	12.20	11.90
% CH3OH	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~
% HCHO	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~
NO. PPM W.	1275.0	1575.0	810.0	1250.0	1675.0	1950.0	2100.0	1950.0	1600.0	1250.0
NO2 PPM W	200.0	175.0	40.0	65.0	100.0	100.0	100.0	200.0	150.0	150.0
NOX PPM W	1425.0	1750.0	850.0	1315.0	1775.0	2050.0	2200.0	2150.0	1750.0	1400.0
HC PPM W	900.0	950.0	2150.0	1950.0	1700.0	1450.0	1100.0	950.0	930.0	925.0
MASS O2 GRMS/HP HR	10670.968	200.292	20.289	22.492	34.904	49.022	87.670	146.402	194.118	228.174
MASS CO GRMS/HP HR	394.581	8.166	134.595	82.400	33.212	24.980	9.219	7.918	8.039	8.437
MASS CO2 GRMS/HP HR	~~0.0~~	881.263	697.442	745.596	773.531	778.539	811.274	858.889	868.356	888.928
MASS NOX GRMS/HP HR	371.546	10.265	3.462	6.018	8.147	9.326	10.649	11.794	10.086	8.536
MASS HC GRMS/HP HR	99.137	2.444	4.403	4.017	3.500	2.970	2.402	2.294	2.368	2.465
EQ.R.CHM.	~~0.0~~	.857	1.115	1.002	1.002	.976	.922	.874	.839	.819
TEST NO.	344	345	346	347	348	349	350	351	352	353

TEST NO.	344	345	346	347	348	349	350	351	352	353
DATE	7.21	7.21	7.21	7.21	7.21	7,21	7.21	7.21	7.21	7.21
HC PPM D	900.9	1070.6	2505.0	2267.8	1967.7	1678.7	1265.0	1085.3	1056.2	1047.4
NOX PPM D	1426.4	1972.2	999.3	1529.3	2054.6	2373.4	2530.0	2456.1	1987.5	1585.3
DRY B TEMP DEG.F.	85.0	85.0	85.0	84.5	84.5	85.0	84.5	84.5	85.0	85.0
WET B TEMP DEG.F.	75.0	75.0	75.0	74.5	74.5	75.0	74.5	74.5	75.0	77.5
BAR.PRESS. INCH. HG.	30.06	30.06	30.06	30.06	30.06	30,06	30.06	30.06	30.06	30.06
IN.COOL.T. DEG.F.	164.2	165.5	170.0	170.9	170.5	169.6	170.5	168.2	166.4	164.2
OUT.COOL.T. DEG.F.	178.1	179.4	185.7	187.5	186.6	185.7	186.2	182.6	181.2	178.1
EXH.PRESS. P.S.I.	.19	.19	.19	.19	.18	.18	.16	.16	.16	.16
AIR FLOW LBS/HR	176.02	176.02	172.29	171.80	171.80	172.29	173.40	174.47	174.42	174.23
FUEL FLOW LBS/HR	11.38	11.53	15.73	15.02	14.02	13.59	13.02	12.88	12.45	12.17
EXH. TEMP. CYL.NO. 1	1001.7	992.7	1051.6	1069.5	1060.9	1052.4	988.4	1007.2	992.7	985.9
CYL.NO. 2	729.8	730.7	766.7	796.8	810.8	806.9	772.7	741.8	733.7	725.5
CYL.NO. 3	1152.3	1203.1	1154.0	[illegible]	1207.4	1213.4	1223.2	1192.4	1165.1	1152.7
CYL.NO. 4	1194.6	1195.4	1208.2	1230.9	1257.5	1266.5	1248.0	1212.1	1185.2	1174.0
INT.MAN.T. CYL.NO.1+2	78.3	77.4	62.8	64.2	66,9	68.3	69.6	64.2	66.0	66.0
CYL.NO.3+4	90.1	89.2	72.8	73.7	76.0	77.8	78.7	73.7	75.5	74.6
CARB. BASE	63.7	62.8	50.0	50.5	52.3	53.2	54.1	50.5	51.0	51.9
NO.D.MOLES PER.MOLE F	1608.944	34.595	21.174	22.182	23.631	23.783	25.330	26.748	28.057	28.750
NO.M.W./D.	1.0010	1.1270	1.1651	1.1630	1.1575	1.1577	1.1500	1.1424	1.1357	1.1324
TEST. NO.	344	345	46	347	348	349	350	351	352	353

TEST NO.	354	355	357	358	359	360	361	363	364	365
% METH.	30.00	30.00	.00	.00	30.00	30.00	30.00	30.00	20.00	20.00
SPARK ADV. DEG. BTDC	54.5	56.0	51.0	55.0	43.0	50.0	54.0	54.0	43.0	50.0
MAN. VAC. INCH.HG.	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
TORQUE FT. LBS.	40.50	37.00	43.40	40.80	49.80	45.80	43.00	41.00	49.00	45.50
ENG. SPEED R.P.M.	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00
EQ. RATIO FUEL/AIR	.821	.794	.899	.849	.985	.900	.857	.819	.996	.893
F/A STOICH	.0836	.0836	.0689	.0689	.0836	.0836	.0836	.0836	.0781	.0781
B.S.F.C. LBS/HP HR	.7794	.8329	.6341	.6470	.7315	.7382	.7602	.7608	.7011	.6895
COR B.H.P.	14.89	13.60	16.00	15.06	18.40	16.93	15.89	15.12	18.08	16.79
COR. BMEP. P.S.I.	29.93	27.35	32.17	30.27	37.00	34.02	31.94	30.40	36.35	33.76
VOL. EF. %	34.99	35.51	33.93	34.54	33.96	34.50	35.04	34.84	33.79	34.43
B.TH.E. %	20.76	19.42	21.12	20.70	22.11	21.91	21.28	21.26	21.60	21.96
% O2	4.55	5.15	3.00	4.00	1.35	3.00	4.00	4.45	1.30	3.10
% CO	.1775	.1354	.1535	.1620	.4997	.1620	.1658	.1658	.4141	.1582
% CO2	11.70	11.40	12.60	11.90	13.40	12.44	11.84	11.74	13.84	13.84
% CH3OH	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~
% HCHO	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~
NO. PPM W.	1150.0	750.0	2050.0	1650.0	2150.0	2300.0	1600.0	1350.0	2550.0	2200.0
NO2 PPM W	150.0	200.0	150.0	150.0	150.0	200.0	200.0	150.0	100.0	100.0
NOX PPM W	1300.0	950.0	2200.0	1800.0	2300.0	2500.0	1800.0	1500.0	2650.0	2300.0
HC PPM W	950.0	960.0	1350.0	1150.0	1350.0	1050.0	950.0	975.0	1550.0	1525.0
MASS O2 GRMS/HP HR	254.448	315.439	154.270	222.335	60.419	149.701	215.862	242.278	58.197	138.969
MASS CO GRMS/HP HR	4.665	9.958	7.358	7.879	19.568	7.073	7.830	7.900	16.219	6.206
MASS CO2 GRMS/HP HR	890.656	960.099	890.911	909.487	824.607	853.544	878.557	878.869	851.919	853.091
MASS NOX GRMS/HP HR	8.177	6.857	12.274	10.878	11.495	13.878	10.916	9.117	12.998	11.312
MASS HC GRMS/HP HR	2.600	2.870	3.358	3.074	3.012	2.583	2.513	2.599	3.443	3.387
EQ.R.CHM.	.804	.779	.874	.827	.961	.870	.825	.808	.962	.882
TEST NO.	354	355	357	358	359	360	361	363	364	365

PAGE 2

TEST NO.	354	355	357	358	359	360	361	363	364	365
DATE	7.21	7.21	7.24	7.24	7.24	7.24	7.24	7.24	7.24	7.24
HC PPM D	1073.6	1081.8	1507.5	1277.0	1554.1	1195.0	1075.0	1102.2	1775.7	1744.2
NOX PPM D	1469.2	1070.5	2456.7	1998.7	2647.6	2845.3	2036.9	1695.7	3035.9	2630.5
DRY B TEMP DEG.F.	85.5	85.5	87.5	88.5	90.0	90.0	90.0	88.0	88.5	88.5
WET B TEMP DEG.F.	77.5	77.5	78.0	76.5	76.0	76.0	76.0	73.5	74.0	74.5
BAR.PRESS. INCH. HG.	30.06	30.06	30.03	30.03	30.03	30.03	30.03	30.03	30.03	30.03
IN.COOL.T. DEG.F.	165.5	165.5	166.0	166.0	171.3	170.0	167.8	166.9	171.8	167.8
OUT.COOL.T. DEG.F.	179.0	179.0	181.2	180.3	187.5	185.3	182.1	189.8	188.0	183.0
EXH.PRESS. P.S.I.	.16	.16	.15	.17	.20	.18	.18	.24	.25	.16
AIR FLOW LBS/HR	175.24	176.82	169.13	171.86	168.51	171.18	173.84	173.51	168.12	171.33
FUEL FLOW LBS/HR	12.02	11.74	10.48	10.06	13.88	12.88	12.45	11.88	13.09	11.95
EXH. TEMP. CYL.NO. 1	993.6	985.4	1246.8	1232.2	1254.5	1204.4	1203.1	1191.1	1252.8	1233.1
CYL.NO. 2	725.1	728.1	749.1	730.2	807.8	745.2	730.2	719.5	793.2	739.7
CYL.NO. 3	1144.1	1131.3	1187.3	1164.2	1209.1	1183.4	1158.7	1141.6	1222.4	1181.3
CYL.NO. 4	1109.3	1164.2	1218.9	1183.9	1245.9	1201.8	1183.9	1130.5	1221.5	1174.0
INT.MAN.T. CYL.NO.1+2	66.4	68.3	92.8	94.6	65.5	67.8	68.7	70.1	75.5	77.8
CYL.NO.3+4	75.1	76.9	104.6	105.5	75.1	76.0	77.4	80.5	87.8	91.0
CARB. BASE	52.3	53.7	83.7	85.1	51.0	52.3	52.8	54.1	61.0	63.7
NO.D.MOLES PER.MOLE F	29.223	29.951	54.204	57.426	24.919	27.531	28.914	29.148	29.832	30.377
NO.M.W./D.	1.1301	1.1269	1.1167	1.1104	1.1512	1.1381	1.1316	1.1305	1.1456	1.1437
TEST. NO.	354	355	357	358	359	360	361	363	364	365

TEST NO.	367	368	369	370	371	372	373	374	375	376
% METH.	.00	.00	.00	.00	.00	.00	.00	.00	.00	20.00
SPARK ADV. DEG. BTDC	38.0	38.0	38.0	40.0	42.0	46.0	50.0	55.0	55.0	38.0
MAN. VAC. INCH.HG.	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
TORQUE FT. LBS.	51.25	51.30	51.00	50.50	48.80	47.00	44.40	38.00	40.80	52.00
ENG. SPEED R.P.M.	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00
EQ. RATIO FUEL/AIR	1.190	1.120	1.078	1.017	.980	.949	.901	.832	.853	1.207
F/A STOICH	.0689	.0689	.0689	.0689	.0689	.0689	.0689	.0689	.0689	.0781
B.S.F.C. LBS/HP HR	.7126	.6680	.6426	.6118	.6101	.6175	.6283	.6749	.6470	.8041
COR B.H.P.	18.84	18.86	18.74	18.57	17.94	17.28	16.33	14.01	15.03	19.15
COR. BMEP. P.S.I.	37.86	37.90	37.68	37.33	36.07	34.74	32.82	28.15	30.21	38.49
VOL. EF. %	33.61	33.70	33.49	33.51	33.51	33.73	34.15	34.16	34.24	33.79
B.TH.E. %	18.80	20.05	20.85	21.89	21.96	21.69	21.32	19.85	20.70	18.83
% O2	.40	.50	.60	.80	1.25	2.05	3.00	4.45	3.90	.45
% CO	5.0722	3.5678	2.2572	.5593	.5664	.2315	.1544	.1544	.1433	5.2070
% CO2	11.80	12.60	13.20	13.70	13.90	13.50	12.80	11.80	12.20	11.60
% CH3OH	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~
% HCHO	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~
NO. PPM W.	615.0	975.0	1400.0	1970.0	2400.0	2500.0	2250.0	1650.0	2100.0	525.0
NO2 PPM W	25.0	50.0	50.0	55.0	200.0	250.0	200.0	150.0	150.0	30.0
NOX PPM W	640.0	1025.0	1450.0	2025.0	2600.0	2750.0	2450.0	1800.0	2250.0	555.0
HC PPM W	2600.0	2400.0	2200.0	2000.0	1850.0	1550.0	1250.0	1300.0	1250.0	2700.0
MASS O2 GRMS/HP HR	17.367	21.276	25.705	35.385	54.417	95.328	150.749	259.971	211.692	19.478
MASS CO GRMS/HP HR	192.911	132.842	84.615	21.647	21.574	9.421	6.791	7.895	6.808	197.206
MASS CO2 GRMS/HP HR	705.243	737.214	777.576	833.215	832.038	863.179	884.394	947.871	910.546	690.379
MASS NOX GRMS/HP HR	3.030	4.771	6.732	9.616	12.493	14.145	13.473	11.422	13.196	2.674
MASS HC GRMS/HP HR	5.571	5.030	4.633	4.325	3.945	3.513	3.043	3.649	3.271	5.841
EQ.R.CHM.	1.160	1.105	1.057	.995	.972	.922	.874	.810	.833	1.170
TEST NO.	367	368	369	370	371	372	373	374	375	376

PAGE 2

TEST NO.	367	368	369	370	371	372	373	374	375	376
DATE	7.25	7.25	7.25	7.25	7.25	7.25	7.25	7.25	7.25	7.25
HC PPM D	2959.1	2729.3	2497.0	2257.6	2092.2	1744.2	1398.3	1442.0	1391.2	3115.5
NOX PPM D	728.4	1165.6	1645.8	2285.8	2940.3	3094.5	2740.6	1996.7	2504.1	640.4
DRY B TEMP DEG.F.	84.0	84.0	84.0	84.5	84.5	84.5	84.5	87.0	86.5	86.0
WET B TEMP DEG.F.	73.0	73.0	73.0	73.0	73.5	73.0	73.5	74.5	74.0	74.0
BAR.PRESS. INCH. HG.	30.03	30.03	30.03	30.03	30.03	30.03	30.03	30.03	30.03	30.03
IN.COOL.T. DEG.F.	176.3	176.3	176.3	176.3	176.3	173.1	171.8	168.7	169.6	174.5
OUT.COOL.T. DEG.F.	192.4	192.0	192.9	192.9	192.9	188.9	187.1	183.0	183.9	190.2
EXH.PRESS. P.S.I.	.16	.19	.20	.20	.19	.20	.20	.20	.19	.22
AIR FLOW LBS/HR	169.62	169.08	168.00	167.96	167.96	169.03	171.18	170.40	170.99	168.89
FUEL FLOW LBS/HR	13.91	13.06	12.48	11.77	11.34	11.06	10.63	9.77	10.06	15.93
EXH. TEMP. CYL.NO. 1	1256.6	1284.9	1300.3	1283.2	1272.5	1087.0	1066.1	1034.9	1033.2	1056.7
CYL.NO. 2	748.2	762.8	781.3	779.1	1114.7	755.1	739.7	721.2	722.5	736.2
CYL.NO. 3	1156.1	1184.7	1203.1	1225.8	1236.5	1221.9	1195.8	1161.2	1169.8	1131.3
CYL.NO. 4	1164.2	1194.1	1214.7	1246.8	1263.9	1060.9	1042.6	995.7	1002.5	997.8
INT.MAN.T. CYL.NO.1,2	91.4	92.8	94.2	95.5	96.4	97.3	97.3	100.1	99.1	72.4
CYL.NO.3,4	104.6	105.5	109.1	109.1	110.0	110.5	110.0	110.9	110.0	81.9
CARB. BASE	81.4	82.4	84.6	86.0	87.8	88.3	88.3	91.0	90.1	57.8
NO.D.MOLES PER.MOLE F	40.773	42.577	44.566	48.326	47.698	50.338	53.458	57.858	56.079	25.149
HC.M.W./D.	1.1361	1.1372	1.1350	1.1288	1.1309	1.1253	1.1186	1.1093	1.1130	1.1539
TEST. NO.	367	368	369	370	371	372	373	374	375	376

TEST NO.	377	378	379	380	381	382	383	384	385	386
% METH.	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	30.00	30.00
SPARK ADV. DEG. BTDC	38.0	38.0	20.0	42.0	46.0	50.0	54.0	54.0	38.0	38.0
MAN. VAC. INCH.HG.	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
TORQUE FT. LBS.	52.50	52.50	51.60	50.20	47.50	45.20	41.00	39.50	52.50	52.50
ENG. SPEED R.P.M.	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00
EQ. RATIO FUEL/AIR	1.136	1.093	1.046	.992	.939	.898	.831	.816	1.133	1.095
F/A STOICH	.0781	.0781	.0781	.0781	.0781	.0781	.0781	.0781	.0836	.0836
B.S.F.C. LBS/HP HR	.7539	.7254	.7020	.6844	.6840	.6941	.7197	.7376	.7936	.7722
COR B.H.P.	19.35	19.35	19.01	18.49	17.51	16.67	15.11	14.55	19.38	19.35
COR. BMEP. P.S.I.	38.90	38.90	38.21	37.17	35.19	33.50	30.38	29.25	38.95	38.90
VOL. EF. %	34.05	34.05	33.81	33.81	33.83	34.18	34.69	34.88	33.68	33.83
B.TH.E. %	20.09	20.88	21.57	22.13	22.14	21.82	21.04	20.53	20.38	20.95
% O2	.50	.60	.80	1.25	2.05	3.05	4.20	4.55	.50	.60
% CO	3.5678	2.3489	1.0042	.5873	.2404	.1544	.1582	.1620	3.4585	2.3953
% CO2	12.50	13.10	13.60	13.90	13.60	12.90	12.10	11.80	12.70	13.20
% CH3OH	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~
% HCHO	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~
NO. PPM W.	925.0	1225.0	1700.0	2200.0	2300.0	2200.0	1400.0	1100.0	900.0	1225.0
NO2 PPM W	25.0	50.0	100.0	125.0	200.0	200.0	150.0	200.0	40.0	50.0
NOX PPM W	950.0	1275.0	1800.0	2325.0	2500.0	2400.0	1550.0	1300.0	940.0	1275.0
HC PPM W	2500.0	2300.0	2000.0	1700.0	1400.0	1200.0	1000.0	950.0	2250.0	2100.0
MASS O2 GRMS/HP HR	21.234	25.523	34.883	53.688	92.291	147.882	225.151	256.234	20.781	25.155
MASS CO GRMS/HP HR	132.582	87.430	38.313	22.073	9.469	6.552	7.421	7.983	125.772	87.873
MASS CO2 GRMS/HP HR	729.936	706.237	815.398	820.896	841.876	860.021	891.891	913.713	725.762	760.945
MASS NOX GRMS/HP HR	4.423	5.976	8.690	11.050	12.564	12.924	9.225	8.341	4.363	5.949
MASS HC GRMS/HP HR	5.303	4.879	4.333	3.629	3.117	2.858	2.615	2.603	4.718	4.434
EQ.R.CHM.	1.110	1.064	1.009	.972	.923	.873	.821	.805	1.105	1.064
TEST NO.	377	378	379	380	381	382	383	384	385	386

PAGE 2

TEST NO.	377	378	379	380	381	382	383	384	385	386
DATE	7.25	7.25	7.25	7.25	7.25	7.25	7.25	7.25	7.25	7.25
HC PPM D	2862.8	2647.9	2294.1	1950.6	1598.8	1361.1	1126.2	1067.0	2621.0	2442.0
NOX PPM D	1095.4	1467.8	2004.7	2667.7	2854.9	2722.2	1745.6	1460.1	1095.0	1482.6
DRY B TEMP DEG.F.	87.0	87.0	86.5	86.5	87.0	87.5	87.0	86.5	88.5	87.0
WET B TEMP DEG.F.	74.0	74.5	74.5	74.5	75.0	74.5	74.5	74.0	75.5	74.5
BAR.PRESS. INCH. HG.	30.03	30.03	30.03	30.03	30.03	30.03	30.03	30.03	30.03	30.03
IN.COOL.T. DEG.F.	175.4	175.8	175.4	176.3	174.9	171.8	170.0	169.1	174.9	174.5
OUT.COOL.T. DEG.F.	192.0	192.4	192.0	192.9	191.1	187.1	184.4	182.6	191.1	190.6
EXH.PRESS. P.S.I.	.22	.20	.22	.21	.20	.19	.20	.18	.21	.20
AIR FLOW LBS/HR	169.87	159.87	168.84	168.84	168.79	170.35	173.07	174.19	167.58	168.79
FUEL FLOW LBS/HR	15.08	14.51	13.80	13.09	12.38	11.95	11.24	11.10	15.87	15.44
EXH. TEMP. CYL.NO. 1	1078.9	1088.7	1092.1	1065.2	1054.5	1029.4	1018.3	1031.1	1058.8	1075.4
CYL.NO. 2	755.5	777.0	798.4	787.7	781.3	758.1	746.5	740.5	777.8	791.5
CYL.NO. 3	1160.8	1178.3	1204.8	1216.8	1221.1	1183.9	1157.0	1148.4	1154.0	1171.9
CYL.NO. 4	1020.8	1034.1	1057.5	1063.9	1048.1	1022.6	997.0	994.4	1014.0	1026.0
INT.MAN.T. CYL.NO.1,2	74.6	76.9	79.6	80.5	81.9	83.3	84.6	84.6	64.2	65.1
CYL.NO.3,4	83.7	86.0	90.1	91.9	93.7	95.5	96.0	96.4	74.2	74.6
CARB. BASE	59.2	61.4	63.7	65.1	66.9	68.3	70.1	70.5	52.3	51.9
NO.D.MOLES PER.MOLE F	26.322	27.398	29.023	29.322	30.751	32.638	34.801	35.672	21.329	22.112
NO.M.W./D.	1.1531	1.1512	1.1471	1.1474	1.1420	1.1343	1.1262	1.1231	1.1649	1.1629
TEST. NO.	377	378	379	380	381	382	383	384	385	386

TEST NO.	387	388	389	390	391	392	393	396	397	398
% METH.	30.00	30.00	30.00	30.00	30.00	30.00	30.00	.00	20.00	30.00
SPARK ADV. DEG. BTDC	40.0	43.0	46.0	50.0	54.0	55.0	56.0	50.0	50.0	50.0
MAN. VAC. INCH.HG.	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
TORQUE FT. LBS.	52.20	50.70	48.50	46.00	41.00	39.00	37.50	44.30	44.50	44.90
ENG. SPEED R.P.M.	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00
EQ. RATIO FUEL/AIR	1.037	.936	.937	.871	.816	.794	.775	.887	.891	.877
F/A STOICH	.0836	.0836	.0836	.0836	.0836	.0836	.0836	.0689	.0781	.0836
B.S.F.C. LBS/HP HR	.7337	.7165	.7203	.7106	.7608	.7806	.8018	.6297	.7134	.7447
COR B.H.P.	19.23	18.68	17.88	16.95	15.10	14.36	13.82	16.27	16.37	16.52
COR. BMEP. P.S.I.	38.06	37.54	35.93	34.08	30.36	28.87	27.78	32.71	32.90	33.21
VOL. EF. %	33.70	33.70	34.05	34.26	34.88	34.97	35.44	34.68	34.75	34.77
B.TH.E. %	22.05	22.51	22.46	22.77	21.26	20.72	20.17	21.27	21.23	21.72
% O2	.30	1.25	2.05	3.00	4.40	4.80	5.20	3.00	3.05	3.00
% CO	1.0042	.6379	.2404	.2448	.1620	.1620	.1620	.1620	.1736	.1799
% CO2	13.70	13.80	13.50	12.90	11.90	11.60	11.36	12.90	12.80	12.86
% CH3OH	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~
% HCHO	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~
NO. PPM W.	1725.0	2150.0	2350.0	2150.0	1350.0	1100.0	800.0	2175.0	2000.0	2075.0
NO2 PPM W	75.0	150.0	150.0	200.0	150.0	200.0	200.0	150.0	200.0	150.0
NOX PPM W	1800.0	2300.0	2500.0	2350.0	1500.0	1300.0	1000.0	2325.0	2200.0	2225.0
HC PPM W	1800.0	1450.0	1160.0	1020.0	950.0	1000.0	1050.0	1200.0	1000.0	950.0
MASS O2 GRMS/HP HR	33.846	52.879	91.517	138.235	236.533	271.333	308.032	149.920	153.198	146.109
MASS CO GRMS/HP HR	37.174	23.614	9.389	9.872	7.620	8.013	8.397	7.084	7.628	7.665
MASS CO2 GRMS/HP HR	796.975	802.703	828.679	817.314	879.609	901.617	925.281	886.404	884.026	861.188
MASS NOX GRMS/HP HR	8.451	10.917	12.422	12.140	9.016	8.415	6.921	12.616	12.313	12.029
MASS HC GRMS/HP HR	4.820	3.073	2.580	2.329	2.504	2.704	3.034	2.908	2.466	2.291
EQ.R.CHM.	1.008	.971	.920	.877	.811	.794	.777	.875	.871	.874
TEST NO.	387	388	389	390	391	392	393	396	397	398

TEST NO.	387	388	389	390	391	392	393	396	397	398
DATE	7.25	7.25	7.25	7.25	7.25	7.25	7.25	7.30	7.30	7.30
HC PPM D	2084.5	1677.0	1334.4	1166.8	1075.6	1128.9	1182.5	1343.6	1133.6	1085.8
NOX PPM D	2064.5	2660.1	2875.9	2688.2	1698.3	1467.5	1126.1	2603.2	2493.9	2543.2
DRY B TEMP DEG.F.	86.5	86.5	87.0	87.0	86.5	86.0	87.0	85.0	86.5	87.0
WET B TEMP DEG.F.	74.5	74.0	75.0	74.5	74.5	74.0	74.0	75.0	75.5	76.0
BAR.PRESS. INCH. HG.	30.03	30.03	30.03	30.03	30.03	30.03	30.03	30.08	30.08	30.08
IN.COOL.T. DEG.F.	174.5	174.9	173.1	170.9	167.8	168.2	167.3	161.5	162.4	162.8
OUT.COOL.T. DEG.F.	191.5	191.1	188.9	186.2	182.1	182.1	181.2	175.8	177.2	177.6
EXH.PRESS. P.S.I.	.20	.22	.20	.20	.20	.20	.18	.16	.16	.17
AIR FLOW LBS/HR	168.31	168.31	169.87	170.94	174.19	174.77	176.80	173.95	173.80	173.75
FUEL FLOW LBS/HR	14.39	13.88	13.31	12.45	11.88	11.60	11.46	10.63	12.09	12.74
EXH. TEMP. CYL.NO. 1	1068.6	1045.2	1032.8	1022.6	1007.6	1011.9	1024.3	1033.2	1075.9	1058.4
CYL.NO. 2	814.6	802.7	771.8	753.8	738.4	736.2	737.1	731.9	764.1	734.1
CYL.NO. 3	1193.3	1210.8	1213.8	1189.0	1151.4	1050.3	1131.3	1164.6	1169.3	1173.2
CYL.NO. 4	1048.6	1055.4	1041.3	1009.8	982.9	978.6	973.9	1013.2	1190.7	1164.2
INT.MAN.T. CYL.NO.1+2	66.9	69.2	71.0	71.9	73.7	74.6	75.1	86.9	72.8	63.7
CYL.NO.3+4	76.0	77.8	80.1	80.5	82.4	83.3	83.7	99.1	85.1	72.8
CARB. BASE	53.2	54.6	56.4	56.4	58.2	58.7	59.2	77.8	57.8	49.1
NO.D.MOLES PER.MOLE F	23.486	23.980	25.245	26.410	28.780	29.494	30.089	53.045	32.897	26.637
NO.M.W./D.	1.1580	1.1506	1.1504	1.1439	1.1322	1.1289	1.1261	1.1196	1.1336	1.1430
TEST. NO.	387	388	389	390	391	392	393	396	397	398

TEST NO.	399	400	401	402	403	414	415	416	417	419
% METH.	20.00	.00	.00	20.00	30.00	.00	.00	.00	.00	.00
SPARK ADV. DEG. BTDC	50.0	50.0	42.5	42.5	42.5	38.0	38.0	38.0	36.0	38.0
MAN. VAC. INCH.HG.	16.00	16.00	15.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
TORQUE FT. LBS.	45.00	44.00	48.80	49.40	49.90	51.50	52.00	52.00	51.70	51.00
ENG. SPEED R.P.M.	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00
EQ. RATIO FUEL/AIR	.890	.899	.987	.986	.977	1.318	1.286	1.197	1.111	1.107
F/A STOICH	.0781	.0689	.0689	.0781	.0836	.0689	.0689	.0689	.0689	.0689
B.S.F.C. LBS/HP HR	.7005	.6425	.6285	.7030	.7375	.7892	.7672	.7095	.6629	.6940
COR B.H.P.	16.54	16.17	17.94	18.16	18.34	18.86	19.05	19.04	18.93	18.70
COR. BMEP. P.S.I.	33.25	32.50	36.06	36.50	36.87	37.91	38.30	38.28	38.06	37.58
VOL. EF. %	34.72	34.70	34.30	34.30	34.30	33.83	34.06	33.82	33.82	35.12
B.TH.E. %	21.47	20.65	21.31	21.54	21.93	16.97	17.46	18.88	20.21	19.30
% O2	2.95	2.95	1.30	1.30	1.25	.35	.40	.40	.50	.50
% CO	.1697	.1620	.6087	.6087	.5192	7.8669	6.7632	5.2070	3.5130	3.6230
% CO2	12.00	12.90	13.80	13.80	13.80	10.00	10.70	11.60	12.50	12.50
% CH3OH	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~
% HCHO	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~
NO. PPM W.	2100.0	2150.0	2275.0	2200.0	2025.0	170.0	275.0	470.0	875.0	910.0
NO2 PPM W	125.0	175.0	125.0	100.0	125.0	15.0	12.0	40.0	45.0	40.0
NOX PPM W	2225.0	2325.0	2400.0	2300.0	2150.0	185.0	287.0	510.0	920.0	950.0
HC PPM W	1050.0	1175.0	1650.0	1400.0	1325.0	3100.0	2900.0	2650.0	2400.0	2400.0
MASS O2 GRMS/HP HR	156.066	150.453	58.625	57.801	54.778	15.877	18.062	17.372	21.313	22.164
MASS CO GRMS/HP HR	7.856	7.229	24.020	23.632	19.908	312.266	267.218	197.874	131.024	140.528
MASS CO2 GRMS/HP HR	873.024	904.633	855.703	843.678	831.537	623.759	664.339	692.720	732.619	761.893
MASS NOX GRMS/HP HR	12.791	12.947	11.789	11.250	10.525	.931	1.411	2.460	4.285	4.588
MASS HC GRMS/HP HR	2.656	2.906	3.[illegible]43	3.092	2.907	6.011	6.444	5.667	5.033	5.237
EQ.R.CHM.	.866	.877	.969	.967	.967	1.270	1.223	1.167	1.104	1.107
TEST NO.	399	400	401	402	403	414	415	416	417	419

PAGE 2

TEST NO.	399	400	401	402	403	414	415	416	417	419
DATE	7.30	7.30	7.30	7.30	7.30	8.01	8.01	8.01	8.01	8.04
HC PPM D	1158.9	1315.6	1365.3	1605.6	1531.4	3517.1	3295.0	3012.8	2726.3	2727.9
NOX PPM D	2503.5	2603.2	2713.2	2637.7	2484.9	209.9	326.1	579.8	1045.1	1079.8
DRY B TEMP DEG.F.	86.0	85.5	86.0	86.0	86.0	83.0	83.5	83.0	83.0	83.0
WET B TEMP DEG.F.	75.0	75.5	74.0	74.0	74.5	72.5	72.0	72.0	72.0	74.0
BAR.PRESS. INCH. HG.	30.08	30.08	30.08	30.03	30.08	30.11	30.11	30.11	30.11	30.08
IN.COOL.T. DEG.F.	157.9	158.8	162.8	163.3	163.7	170.5	171.3	172.2	173.1	163.7
OUT.COOL.T. DEG.F.	172.2	173.6	179.0	179.4	179.4	185.3	187.1	187.5	189.3	179.4
EXH.PRESS. P.S.I.	.18	.16	.15	.15	.17	.10	.10	.18	.17	.33
AIR FLOW LBS/HR	173.85	173.90	171.71	171.71	171.71	170.48	171.48	170.44	170.44	176.81
FUEL FLOW LBS/HR	12.09	10.77	11.68	13.23	14.02	15.48	15.20	14.05	13.06	13.48
EXH. TEMP. CYL.NO. 1	1041.7	1054.5	1090.8	1075.0	1084.4	1040.0	1046.9	1070.7	1087.0	1059.7
CYL.NO. 2	721.2	737.1	796.2	793.7	783.4	1082.3	1103.6	1131.3	1150.1	1146.3
CYL.NO. 3	1148.0	1146.3	1180.5	1176.6	1168.9	1105.7	1122.0	1148.0	1171.1	1156.5
CYL.NO. 4	1167.3	1196.3	1214.7	1216.8	1215.5	1146.7	1164.6	1195.4	1212.9	1208.7
INT.MAN.T. CYL.NO.1,2	71.4	86.9	86.0	71.0	60.5	85.1	86.9	88.7	91.0	84.6
CYL.NO.3,4	62.8	98.7	98.7	82.8	70.1	97.8	98.7	101.4	103.2	98.7
CARB. BASE	56.9	78.3	77.4	55.5	46.4	75.5	76.9	79.2	81.4	78.3
NO.D.MOLES PER.MOLE F	35.043	53.056	47.961	29.550	24.201	38.422	39.342	40.916	42.983	42.694
NO.M.W./D.	1.1252	1.1197	1.1305	1.1468	1.1558	1.1345	1.1362	1.1369	1.1359	1.1366
TEST. NO.	399	400	401	402	403	414	415	416	417	419

TEST NO.	420	421	422	423	424	425	426	427	430	431
% METH.	20.00	30.00	30.00	30.00	30.00	20.00	20.00	20.00	.00	.00
SPARK ADV. DEG. BTDC	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0
MAN. VAC. INCH.HG.	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
TORQUE FT. LBS.	52.00	53.00	52.50	53.20	53.00	52.50	53.00	52.20	50.20	50.80
ENG. SPEED R.P.M.	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00
EQ. RATIO FUEL/AIR	1.102	1.097	1.178	1.285	1.343	1.378	1.302	1.213	1.128	1.198
F/A STOICH	.0781	.0836	.0836	.0836	.0836	.0781	.0781	.0781	.0689	.0689
B.S.F.C. LBS/HP HR	.7683	.8003	.8649	.9308	.9767	.9456	.8875	.8296	.6827	.7189
COR B.H.P.	19.06	19.45	19.26	19.52	19.46	19.26	19.45	19.15	18.45	18.67
COR. BMEP. P.S.I.	38.32	39.09	38.72	39.24	39.11	38.72	39.09	38.50	37.10	37.54
VOL. EF. %	35.12	35.06	34.96	34.96	34.98	34.96	35.06	34.64	33.55	33.65
B.TH.E. %	19.71	20.21	18.70	17.38	16.56	16.01	17.06	18.25	19.62	18.63
% O2	.50	.50	.40	.40	.40	.40	.40	.40	.50	.40
% CO	3.5678	3.4043	5.1392	6.8544	7.8669	8.0950	6.8544	5.2070	3.7908	5.2070
% CO2	12.40	12.40	11.70	10.70	9.90	9.80	10.64	11.60	12.50	11.70
% CH3OH	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~
% HCHO	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~
NO. PPM W.	875.0	860.0	480.0	245.0	165.0	170.0	250.0	450.0	900.0	555.0
NO2 PPM W	25.0	~~0~~	20.0	20.0	10.0	~~0~~	~~0~~	~~0~~	40.0	25.0
NOX PPM W	900.0	860.0	500.0	265.0	175.0	170.0	250.0	450.0	940.0	580.0
HC PPM W	2200.0	2100.0	2350.0	2700.0	2950.0	3000.0	2750.0	2480.0	2450.0	2600.0
MASS O2 GRMS/HP HR	21.820	21.440	17.384	17.919	18.552	19.109	18.364	17.889	21.573	17.505
MASS CO GRMS/HP HR	136.241	127.733	195.431	268.670	319.252	338.371	275.356	203.760	143.114	199.388
MASS CO2 GRMS/HP HR	744.078	731.117	699.160	659.068	631.337	643.718	671.681	713.324	741.585	704.036
MASS NOX GRMS/HP HR	4.306	4.015	2.424	1.348	.910	.876	1.241	2.178	4.423	2.770
MASS HC GRMS/HP HR	4.792	4.529	5.154	6.098	6.876	7.141	6.306	5.544	5.208	5.608
EQ.R.CHM.	1.108	1.104	1.169	1.236	1.284	1.286	1.233	1.171	1.112	1.165
TEST NO.	420	421	422	423	424	425	426	427	430	431

PAGE 2

TEST NO.	420	421	422	423	424	425	426	427	430	431
DATE	8.04	8.04	8.04	8.04	8.04	8.04	8.04	8.04	8.05	8.05
HC PPM D	2535.2	2438.7	2737.9	3143.0	3422.9	3451.2	3171.3	2862.2	2787.0	2958.6
NOX PPM D	1057.1	998.7	582.5	308.5	203.1	195.6	288.3	519.4	1069.3	660.0
DRY B TEMP DEG.F.	83.0	84.0	86.0	84.0	84.5	84.0	84.0	84.0	86.0	86.0
WET B TEMP DEG.F.	74.0	74.0	74.0	74.0	74.5	74.0	74.0	74.0	75.5	75.5
BAR.PRESS. INCH. HG.	30.08	30.08	30.08	30.08	30.08	30.08	30.08	30.08	30.08	30.08
IN.COOL.T. DEG.F.	165.5	163.7	162.8	162.8	163.7	162.8	164.2	166.0	170.0	169.6
OUT.COOL.T. DEG.F.	181.7	180.3	179.0	178.5	178.5	177.6	179.9	182.1	185.7	185.7
EXH.PRESS. P.S.I.	.36	.34	.34	.28	.26	.28	.28	.30	.26	.28
AIR FLOW LBS/HR	176.81	176.18	175.65	175.65	175.60	175.65	176.18	174.04	167.95	168.49
FUEL FLOW LBS/HR	15.22	16.16	17.30	18.87	19.72	18.91	17.92	16.50	13.06	13.91
EXH. TEMP. CYL.NO. 1	1058.4	1053.7	1029.0	1000.0	982.0	995.1	~~29.0~~	~~29.0~~	1043.0	1016.2
CYL.NO. 2	1135.6	1129.2	1099.3	1061.8	1036.2	1037.5	1062.6	~~29.0~~	1117.3	1095.1
CYL.NO. 3	1149.3	1146.3	1114.3	1080.6	1056.7	1058.4	~~29.0~~	~~29.0~~	1150.6	1122.4
CYL.NO. 4	1201.8	1197.1	1160.8	1130.1	1111.3	1111.7	~~29.0~~	~~29.0~~	1210.4	1184.7
INT.MAN.T. CYL.NO.1,2	68.3	59.2	56.4	53.7	52.8	59.2	61.0	65.1	88.7	87.4
CYL.NO.3,4	80.1	70.1	66.9	63.7	62.3	68.3	70.5	74.2	101.9	100.1
CARB. BASE	54.1	47.3	45.9	44.1	43.2	47.8	49.1	51.9	79.2	77.4
NO.D.MOLES PER.MOLE F	26.540	21.824	20.466	19.601	19.340	23.603	24.171	25.187	42.246	40.691
NO.M.W./D.	1.1524	1.1613	1.1651	1.1641	1.1603	1.1504	1.1532	1.1541	1.1375	1.1379
TEST. NO.	420	421	422	423	424	425	426	427	430	431

TEST NO.	432	433	434	435	436	437	438	439	440	441
% METH.	.00	.00	20.00	20.00	20.00	20.00	30.00	30.00	30.00	30.00
SPARK ADV. DEG. BTDC	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0
MAN. VAC. INCH.HG.	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
TORQUE FT. LBS.	50.80	51.00	52.00	52.00	51.90	51.90	52.20	52.00	52.20	52.20
ENG. SPEED R.P.M.	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00
EQ. RATIO FUEL/AIR	1.240	1.316	1.138	1.192	1.255	1.336	1.090	1.124	1.207	1.287
F/A STOICH	.0689	.0689	.0781	.0781	.0781	.0781	.0836	.0836	.0836	.0836
B.S.F.C. LBS/HP HR	.7558	.8043	.7611	.7970	.8488	.9063	.7767	.8013	.8627	.9200
COR B.H.P.	18.67	18.75	19.12	19.12	19.09	19.08	19.19	19.12	19.20	19.20
COR. BMEP. P.S.I.	37.54	37.69	38.43	38.43	38.37	38.35	38.57	38.44	38.59	38.59
VOL. EF. %	34.19	34.40	33.87	33.87	34.21	34.30	33.87	33.78	34.00	34.00
B.TH.E. %	17.72	16.65	19.90	19.00	17.84	16.71	20.83	20.19	18.75	17.58
% O2	.35	.40	.50	.50	.45	.45	.60	.50	.45	.45
% CO	6.0757	7.7564	3.4912	5.0058	6.4991	7.8224	2.3028	3.5678	5.2754	6.9472
% CO2	10.60	10.10	12.56	11.70	10.80	9.90	13.20	12.80	11.70	10.60
% CH3OH	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~
% HCHO	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~	~~.00~~
NO. PPM W.	315.0	220.0	870.0	515.0	300.0	~~.0~~	1100.0	790.0	~~.0~~	~~.0~~
NO2 PPM W	10.0	~~.0~~	30.0	~~.0~~	~~.0~~	~~.0~~	50.0	~~.0~~	~~.0~~	~~.0~~
NOX PPM W	325.0	220.0	900.0	515.0	300.0	~~.0~~	1150.0	790.0	~~.0~~	~~.0~~
HC PPM W	2900.0	3050.0	2225.0	2450.0	2700.0	3000.0	1950.0	2100.0	2350.0	2700.0
MASS O2 GRMS/HP HR	15.560	18.509	21.502	21.613	19.985	20.799	25.477	20.738	19.353	19.932
MASS CO GRMS/HP HR	259.657	314.042	131.368	189.335	252.557	316.359	85.559	129.479	198.519	269.250
MASS CO2 GRMS/HP HR	660.192	642.607	742.686	695.399	659.517	629.173	770.673	729.962	691.870	645.577
MASS NOX GRMS/HP HR	1.565	1.083	4.260	2.408	1.440	~~.000~~	5.444	3.585	~~.000~~	~~.000~~
MASS HC GRMS/HP HR	6.348	6.938	4.781	5.293	5.988	6.907	4.168	4.402	5.104	6.026
EQ.R.CHM.	1.222	1.261	1.105	1.158	1.217	1.274	1.060	1.106	1.172	1.239
TEST NO.	432	433	434	435	436	437	438	439	440	441

PAGE 2

TEST NO.	432	433	434	435	436	437	438	439	440	441
DATE	8.05	8.05	8.05	8.05	8.05	8,05	8.05	8.05	8.05	8.05
HC PPM D	3296.6	3461.9	2563.5	2827.2	3113.1	3450.3	2266.5	2450.6	2740.0	3141.3
NOX PPM D	369.4	249.7	1035.2	594.3	345.9	.0	1336.7	921.9	.0	.0
DRY B TEMP DEG.F.	86.0	86.0	86.0	86.0	86.5	86.0	86.0	86.5	86.5	86.5
WET B TEMP DEG.F.	75.5	75.5	76.0	76.0	75.5	75.5	75.5	76.0	76.0	75.5
BAR.PRESS. INCH. HG.	30.08	30.08	30.08	30.08	30.08	30.08	30.08	30.08	30.08	30.08
IN.COOL.T. DEG.F.	168.7	167.3	170.5	171.8	169.6	168.2	171.3	171.3	170.5	170.0
OUT.COOL.T. DEG.F.	164.4	162.6	231.4	187.5	184.8	183.0	187.5	187.1	185.7	185.3
EXH.PRESS. P.S.I.	.28	.28	.28	.28	.28	.30	.30	.30	.30	.30
AIR FLOW LBS/HR	171.18	172.25	169.57	169.57	171.13	171.71	169.57	168.98	170.06	170.06
FUEL FLOW LBS/HR	14.63	15.63	15.08	15.79	16.78	17.92	15.44	15.87	17.15	18.29
EXH. TEMP. CYL.NO. 1	1000.0	935.0	1061.8	1030.2	996.5	986.3	1080.6	1056.7	1029.0	1002.1
CYL.NO. 2	1066.9	1005.5	1105.3	1081.4	1054.5	1028.1	1121.1	1101.9	1071.6	1039.6
CYL.NO. 3	1093.8	1076.7	1140.7	1113.4	1087.0	1060.9	1157.8	1136.9	1109.6	1077.1
CYL.NO. 4	1155.7	1142.0	1206.1	1178.3	1152.7	1119.0	1216.8	1200.5	1169.8	1130.5
INT.MAN.T. CYL.NO.1,2	85.1	83.7	71.4	69.6	66.4	63.7	62.3	61.0	58.2	56.4
CYL.NO.3,4	97.3	95.5	81.9	79.6	75.5	73.3	73.3	71.4	68.3	66.0
CARB. BASE	75.1	73.3	56.9	55.5	53.2	51.4	50.5	49.6	47.8	46.4
NO.D.MOLES PER.MOLE F	30.318	38.456	26.400	25.342	24.447	23.828	22.266	21.082	20.304	19.609
NO.M.W./D.	1.1367	1.1351	1.1535	1.1540	1.1530	1.1501	1.1623	1.1669	1.1660	1.1634
TEST. NO.	432	433	434	435	436	437	438	439	440	441

Table 4 Statistical Significance of Test Results - FORMAT

Experimental Error Sum of Squares, EESS:

Number of Observations, n:

Functional Form	Independent Variables and Their Equation (2 or 3) Coefficients' t values					Sum of Squares Deviation About Regression	
	Φ_c	Φ_c^2	Φ_c^3	M	$M\Phi_c$		
1	$t_{1,1}$	$t_{2,1}$					
2	$t_{1,2}$	$t_{2,2}$	$t_{3,2}$				
3	$t_{1,3}$	$t_{2,3}$		$t_{4,3}$			
4	$t_{1,4}$	$t_{2,4}$	$t_{3,4}$	$t_{4,4}$			
5	$t_{1,5}$	$t_{2,5}$			$t_{5,5}$		
6	$t_{1,6}$	$t_{2,6}$	$t_{3,6}$		$t_{5,6}$		
	Approximate Significance Level α					$F_{\alpha', \nu_1, \nu_2}$	α'
1	$\alpha_{1,1}$	$\alpha_{2,1}$					
2	$\alpha_{1,2}$	$\alpha_{2,2}$	$\alpha_{3,2}$				
3	$\alpha_{1,3}$	$\alpha_{2,3}$		$\alpha_{4,3}$			
4	$\alpha_{1,4}$	$\alpha_{2,4}$	$\alpha_{3,4}$	$\alpha_{4,4}$			
5	$\alpha_{1,5}$	$\alpha_{2,5}$			$\alpha_{5,5}$		
6	$\alpha_{1,6}$	$\alpha_{2,6}$	$\alpha_{3,6}$		$\alpha_{5,6}$		

Table 6 Statistical Significance of Test Results - BRAKE THERMAL EFFICIENCY

Experimental Error Sum of Squares, EESS: 2.15

Number of Observations, n: 83

Functional Form	Independent Variables and Their Equation (2 or 3) Coefficients' t values					Sum of Squares Deviation About Regression	
	Φ_c	Φ_c^2	Φ_c^3	M	$M\Phi_c$		
1							
2	3.3	2.9	2.4			12.0	
3							
4	3.5	3.1	2.6	1.8		11.4	
5							
6	3.5	3.1	2.6		1.7	11.7	
	Approximate Significance Level α					$F_{\alpha', \nu_1, \nu_2}$	α'
1							
2	0.001	0.006	0.019			1.36	0.21
3							
4	<0.001	0.002	0.01	0.08		1.28	0.28
5							
6	<0.001	0.002	0.01		0.095	1.33	0.24

Table 5 Statistical Significance of Test Results - TORQUE

Experimental Error Sum of Squares, EESS: 3.45

Number of Observations, n: 83

Functional Form	Independent Variables and Their Equation (2 or 3) Coefficients' t values Φ_c	Φ_c^2	Φ_c^3	M	$M\Phi_c$	Sum of Squares Deviation About Regression
1	15.8	14.5				47.5
2						
3	25.6	23.6		11.9		17.0
4						
5	24.5	22.5			11.3	18.1
6						

	Approximate Significance Level α					$F_{\alpha', \nu_1, \nu_2}$	α'
1	<0.001	<0.001				3.7	≈0.001
2							
3	<0.001	<0.001		<0.001		1.15	0.49
4							
5	<0.001	<0.001			<0.001	1.25	0.31
6							

Table 6 Statistical Significance of Test Results - BRAKE THERMAL EFFICIENCY

Experimental Error Sum of Squares, EESS: 2.15

Number of Observations, n: 83

Functional Form	Independent Variables and Their Equation (2 or 3) Coefficients' t values					Sum of Squares Deviation About Regression	
	Φ_c	Φ_c^2	Φ_c^3	M	$M\Phi_c$		
1							
2	3.3	2.9	2.4			12.0	
3							
4	3.5	3.1	2.6	1.8		11.4	
5							
6	3.5	3.1	2.6		1.7	11.7	
	Approximate Significance Level α					$F_{\alpha', \nu_1, \nu_2}$	α'
1							
2	0.001	0.006	0.019			1.36	0.21
3							
4	<0.001	0.002	0.01	0.08		1.28	0.28
5							
6	<0.001	0.002	0.01		0.095	1.33	0.24

Table 7 Statistical Significance of Test Results - NITRIC OXIDES (NO_x) MASS EMISSIONS

Experimental Error Sum of Squares, EESS: 5.85

Number of Observations, n: 66

Functional Form	Independent Variables and Their Equation (2 or 3) Coefficients' t values Φ_c	Φ_c^2	Φ_c^3	M	$M\Phi_c$	Sum of Squares Deviation About Regression
1						
2	5.15	5.09	4.89			57.1
3						
4	5.07	5.01	4.79	2.81		52.1
5						
6	5.12	5.06	4.84		2.89	50.6

	Approximate Significance Level α					$F_{\alpha', \nu_1, \nu_2}$	α'
1							
2	<0.001	<0.001	<0.001			2.75	≈0.001
3							
4	<0.001	<0.001	<0.001	<0.008		2.53	≈0.001
5							
6	<0.001	<0.001	<0.001		0.007	2.44	0.001

Table 8 Statistical Significance of Test Results - FID TOTAL HC MASS EMISSIONS

Experimental Error Sum of Squares, EESS: 1.4

Number of Observations, n: 83

Functional Form	Independent Variables and Their Equation (2 or 3) Coefficients' t values					Sum of Squares Deviation About Regression
	Φ_c	Φ_c^2	Φ_c^3	M	$M\Phi_c$	
1	22.3					13.5
2	27.1			6.8		8.6
3	27.8				6.7	8.7
4						
5						
6						

	Approximate Significance Level α					$F_{\alpha', \nu_1, \nu_2}$	α'
1	<0.001					2.47	≈0.001
2	<0.001			<0.001		1.49	0.15
3	<0.001				<0.001	1.51	0.14
4							
5							
6							

Table 9 Statistical Significance of Test Results - CARBON MONOXIDE MASS EMISSIONS

Experimental Error Sum of Squares, EESS: 6432

Number of Observations, n: 78

Functional Form	Independent Variables and Their Equation (2 or 3) Coefficients' t values					Sum of Squares Deviation About Regression
	Φ_c	Φ_c^2	Φ_c^3	M	$M\Phi_c$	
1	1.77	2.86				36600
2	0.918	0.895	0.794			36600
3	3.38	4.85		7.87		20100
4	0.903	0.835	0.662	7.70		20400
5	3.35	4.75			7.42	21100
6	0.791	0.721	0.55		7.25	21500

	Approximate Significance Level α					$F_{\alpha', \nu_1, \nu_2}$	α'
1	0.094	0.006				1.46	0.165
2	>0.1	>0.1	>0.1			1.48	0.160
3	0.001	<0.001		<0.001		0.67	>0.5
4	>0.1	>0.1	>0.1	<0.001		0.70	>0.5
5	0.001	<0.001			<0.001	0.72	>0.5
6	>0.1	>0.1	>0.1		<0.001	0.75	>0.5

Table 10 Nominal Values of Operating Parameters for Type I and II Tests with Indolene Fuel.

Vehicle Speed, mph(km/hr)	30(48)	40(64)	52(84)	52(84)
Load Level	cruise	cruise	cruise	accelera-tion
Engine Speed, RPM	1150	1500	2000	2000
Torque, ft lb_f (n·m)	23.5(31.9)	32.5(44.1)	46.5(63.0)	89.5(121)
Spark Advance, deg BTDC	44.5	47.5	51.0	34.0
$P_{manifold,}$ in.Hg (kPa)	19(64)	18(60)	16(54)	10(34)

LIST OF FIGURES

FIGURE	TITLE	PAGE
1	Chemical vs. Mass Fuel-Air Equivalence Ratio for Indolene Fuel, 2000 RPM, 16 in. Hg, MBT Spark.	92
2	Chemical vs. Mass Fuel-Air Equivalence Ratio for 20 Percent Methanol-Indolene Blend Fuel, 2000 RPM, 16 in. Hg, MBT Spark.	93
3	Chemical vs. Mass Fuel-Air Equivalence Ratio for 30 Percent Methanol-Indolene Blend Fuel, 2000 RPM, 16 in. Hg, MBT Spark.	94
4	Superimposes the Φ_c versus Φ_m Regression Analysis Curves for 0, 20 and 30%M Blends, 2000 RPM, 16 in. Hg, MBT Spark.	95
5	Brake Thermal Efficiency versus Spark Advance (2000 RPM and 16 in. Hg (54 kPa) manifold vacuum).	96
6	MBT Spark Advance versus Equivalence Ratio, Φ_c, for 0, 20 and 30%M Blends at 2000 RPM and 16 in. Hg (54 kPa) manifold vacuum.	101
7	Torque vs. Chemical Fuel-Air Equivalence Ratio for Indolene Fuel, 2000 RPM, 16 in. Hg, MBT Spark.	102
8	Torque vs. Chemical Fuel-Air Equivalence Ratio for 20 Percent Methanol-Indolene Blend Fuel, 2000 RPM, 16 in. Hg, MBT Spark.	103
9	Torque vs. Chemical Fuel-Air Equivalence Ratio for 30 Percent Methanol-Indolene Blend Fuel, 2000 RPM, 16 in. Hg, MBT Spark.	104
10	Equation (1) Regression Model Curves for Torque vs. Chemical Fuel-Air Equivalence Ratio, 2000 RPM, 16 in. Hg, MBT Spark.	105
11	Brake Thermal Efficiency vs. Chemical Fuel-Air Equivalence Ratio for Indolene Fuel, 2000 RPM, 16 in. Hg, MBT Spark.	106
12	Brake Thermal Efficiency vs. Chemical Fuel-Air Equivalence Ratio for 20 Percent Methanol-Indolene Blend Fuel, 2000 RPM, 16 in. Hg, MBT Spark.	107
13	Brake Thermal Efficiency vs. Chemical Fuel-Air Equivalence Ratio for 30 Percent Methanol-Indolene Blend Fuel, 2000 RPM, 16 in. Hg, MBT Spark.	108

LIST OF FIGURES - Cont.

FIGURE	TITLE	PAGE
14	Equation (1) Regression Model Curves for Brake Thermal Efficiency vs. Chemical Fuel-Air Equivalence Ratio, 2000 RPM, 16 in. Hg, MBT Spark.	109
15	Volumetric Efficiency vs. Chemical Fuel-Air Equivalence Ratio for Indolene Fuel, 2000 RPM, 16 in. Hg, MBT Spark.	110
16	Volumetric Efficiency vs. Chemical Fuel-Air Equivalence Ratio for 20 Percent Methanol-Indolene Blend Fuel, 2000 RPM, 16 in. Hg, MBT Spark.	111
17	Volumetric Efficiency vs. Chemical Fuel-Air Equivalence Ratio for 30 Percent Methanol-Indolene Blend Fuel, 2000 RPM, 16 in. Hg, MBT Spark.	112
18	CO Mass Emissions vs. Chemical Fuel-Air Equivalence Ratio for Indolene Fuel, 2000 RPM, 16 in. Hg, MBT Spark.	113
19	CO Mass Emissions vs. Chemical Fuel-Air Equivalence Ratio for 20 Percent Methanol-Indolene Blend Fuel, 2000 RPM, 16 in. Hg, MBT Spark.	114
20	CO Mass Emissions vs. Chemical Fuel-Air Equivalence Ratio for 30 Percent Methanol-Indolene Blend Fuel, 2000 RPM, 16 in. Hg, MBT Spark.	115
21	Equation (1) Regression Model Curves for CO Mass Emissions vs. Chemical Fuel-Air Equivalence Ratio, 2000 RPM, 16 in. Hg, MBT Spark.	116
22	NO_x Mass Emissions vs. Chemical Fuel-Air Equivalence Ratio for Indolene Fuel, 2000 RPM, 16 in. Hg, MBT Spark.	117
23	NO_x Mass Emissions vs. Chemical Fuel-Air Equivalence Ratio for 20 Percent Methanol-Indolene Blend Fuel, 2000 RPM, 16 in. Hg, MBT Spark.	118
24	NO_x Mass Emissions vs. Chemical Fuel-Air Equivalence Ratio for 30 Percent Methanol-Indolene Blend Fuel, 2000 RPM, 16 in. Hg, MBT Spark.	119
25	Equation (1) Regression Model Curves for NO_x Mass Emissions vs. Chemical Fuel-Air Equivalence Ratio, 2000 RPM, 16 in. Hg, MBT Spark.	120

LIST OF FIGURES - Cont.

FIGURE	TITLE	PAGE
26	FID HC Mass Emissions vs. Chemical Fuel-Air Equivalence Ratio for Indolene Fuel, 2000 RPM, 16 in. Hg, MBT Spark.	121
27	FID HC Mass Emissions vs. Chemical Fuel-Air Equivalence Ratio for 20 Percent Methanol-Indolene Blend Fuel, 2000 RPM, 16 in. Hg, MBT Spark.	122
28	FID HC Mass Emissions vs. Chemical Fuel-Air Equivalence Ratio for 30 Percent Methanol-Indolene Blend Fuel, 2000 RPM, 16 in. Hg, MBT Spark.	123
29	Equation (1) Regression Model Curves for FID HC Mass Emissions vs. Chemical Fuel-Air Equivalence Ratio, 2000 RPM, 16 in. Hg, MBT Spark.	124
30	CO_2 Mass Emissions vs. Chemical Fuel-Air Equivalence Ratio for Indolene Fuel, 2000 RPM, 16 in. Hg, MBT Spark.	125
31	CO_2 Mass Emissions vs. Chemical Fuel-Air Equivalence Ratio for 20 Percent Methanol-Indolene Blend Fuel, 2000 RPM, 16 in. Hg, MBT Spark.	126
32	CO_2 Mass Emissions vs. Chemical Fuel-Air Equivalence Ratio for 20 Percent Methanol-Indolene Blend Fuel, 2000 RPM, 16 in. Hg, MBT Spark.	127
33	Equation (1) Regression Model Curves for CO_2 Mass Emissions vs. Chemical Fuel-Air Equivalence Ratio, 2000 RPM, 16 in. Hg, MBT Spark.	128
34	Oxygen Mass Emissions vs. Chemical Fuel-Air Equivalence Ratio for Indolene Fuel, 2000 RPM, in. Hg, MBT Spark.	129
35	Oxygen Mass Emissions vs. Chemical Fuel-Air Equivalence Ratio for 20 Percent Methanol-Indolene Blend Fuel, 2000 RPM, 16 in. Hg, MBT Spark.	130
36	Oxygen Mass Emissions vs. Chemical Fuel-Air Equivalence Ratio for 30 Percent Methanol-Indolene Blend Fuel, 2000 RPM, 16 in. Hg, MBT Spark.	131
37	Equation (1) Regression Model Curves for O_2 Mass Emissions vs. Chemical Fuel-Air Equivalence Ratio, 2000 RPM, 16 in. Hg, MBT Spark.	132

LIST OF FIGURES - Cont.

FIGURE	TITLE	PAGE
38	Individual Cylinder Exhaust Oxygen Emissions versus Percent Methanol, 2000 RPM, 16 in. Hg (54 kPa), MBT Spark.	133
39	Oxygen Percent vs. Chemical Fuel-Air Equivalence Ratio for Indolene Fuel, 2000 RPM, 16 in. Hg, MBT Spark.	134
40	Oxygen Percent vs. Chemical Fuel-Air Equivalence Ratio for 20 Percent Methanol-Indolene Blend Fuel, 2000 RPM, 16 in. Hg, MBT Spark.	135
41	Oxygen Percent vs. Chemical Fuel-Air Equivalence Ratio for 30 Percent Methanol-Indolene Blend Fuel, 2000 RPM, 16 in. Hg, MBT Spark.	136
42	Illustrates the Effect of Methanol on Geometric Distribution, 2000 RPM, 16 in. Hg, MBT Spark, $\Phi_C \approx 0.97$.	137
43	Illustrates the Effect of Methanol on Geometric Distribution, 2000 RPM, 16 in. Hg, MBT Spark, $\Phi_C \approx 0.87$.	138
44	Illustrates the Effect of Methanol on Maximum Spread in Geometric Fuel-Air Equivalence Ratios as Determined from Figures 42 and 43.	139
45	Illustrates the Reduction in Fuel-Air Equivalence Ratio when Methanol Blends are Substituted for Indolene with No Engine Adjustments (Type I Tests).	140
46a	Illustrates the Reduction in Torque Occurring when Methanol Blends are Substituted for Indolene with No Engine Adjustments (Type I Tests).	141
46b	Illustrates the Reduction in Engine Speed Occurring when Methanol Blends are Substituted for Indolene with No Engine Adjustments (Type I Tests).	142
47	Brake Thermal Efficiency When Methanol Blends are Substituted for Indolene with No Engine Adjustments (Type I Tests).	143
48a	Carbon Monoxide Volume Emissions when Methanol Blends are Substituted for Indolene with No Engine Adjustments (Type I Tests).	144

LIST OF FIGURES - Cont.

FIGURE	TITLE	PAGE
48b	Carbon Monoxide Mass Emissions When Methanol Blends are Substituted for Indolene with No Engine Adjustments (Type I Tests).	145
49a	Illustrates the Reduction in Nitric Oxide Mass Emissions Occurring when Methanol Blends are Substituted for Indolene with No Engine Adjustments (Type I Tests).	146
49b	Illustrates the Reduction in Nitric Oxide Volume Emissions when Methanol Blends are Substituted for Indolene with No Engine Adjustments (Type I Tests).	147
50a	Illustrates the Reduction in FID HC Volume Emissions when Methanol Blends are Substituted for Indolene with No Engine Adjustments (Type I Tests).	148
50b	Illustrates the Reduction in FID HC Mass Emissions when Methanol Blends are Substituted for Indolene with No Engine Adjustments (Type I Tests).	149
50c	Shows the Effect of Fuel-Air Equivalence Ratio on FID HC Mass Emissions for the Type I Tests.	150
51	Shows the Reduced Manifold Vacuum Required for Methanol Blends to Attain the Same Torque and Engine Speed as Found with Indolene (Type II Tests).	151
52	Shows the Fuel-Air Equivalence Ratio Decrease (Blend Leaning Effect) as a Function of Methanol Blend Level for the Type II Tests.	152
53	Shows the Increased Efficiency Obtained with Blends at Equal-to-Indolene Torque and Engine Speed Operation (Type II Tests).	153
54	Shows the Oxygen Emissions as a Function of Methanol Blend Level for the Type II Tests.	155
55a	Shows the Effect of Methanol Addition on CO Volume Emissions at Equal-to-Gasoline Fueled Torque and Engine Speed (Type II Tests).	156

LIST OF FIGURES - Cont.

FIGURE	TITLE	PAGE
55b	Shows the Effect of Methanol Addition on CO Mass Emissions at Equal-to-Gasoline Fueled Torque and Engine Speed (Type II Tests).	157
56a	Illustrates the Effect of Fuel-Air Equivalence Ratio on the CO Volume Emissions for the 0%M Type II Tests.	158
56b	Shows the CO NDIR Analyzer Response for Tests Numbered 139 through 144 (Type II Tests).	159
57	Illustrates the Reduction in Nitric Oxide Mass Emissions with Methanol Blends at Equal-to-Indolene Torque and Engine Speed Operation (Type II Tests).	160
58a	Illustrates the Reduction in FID HC Volume Emissions with Methanol Blends at Equal-to-Indolene Torque and Engine Speed Operation (Type II Tests).	162
58b	Illustrates the Reduction in FID HC Mass Emissions with Methanol Blends at Equal-to-Indolene Torque and Engine Speed Operation (Type II Tests).	164

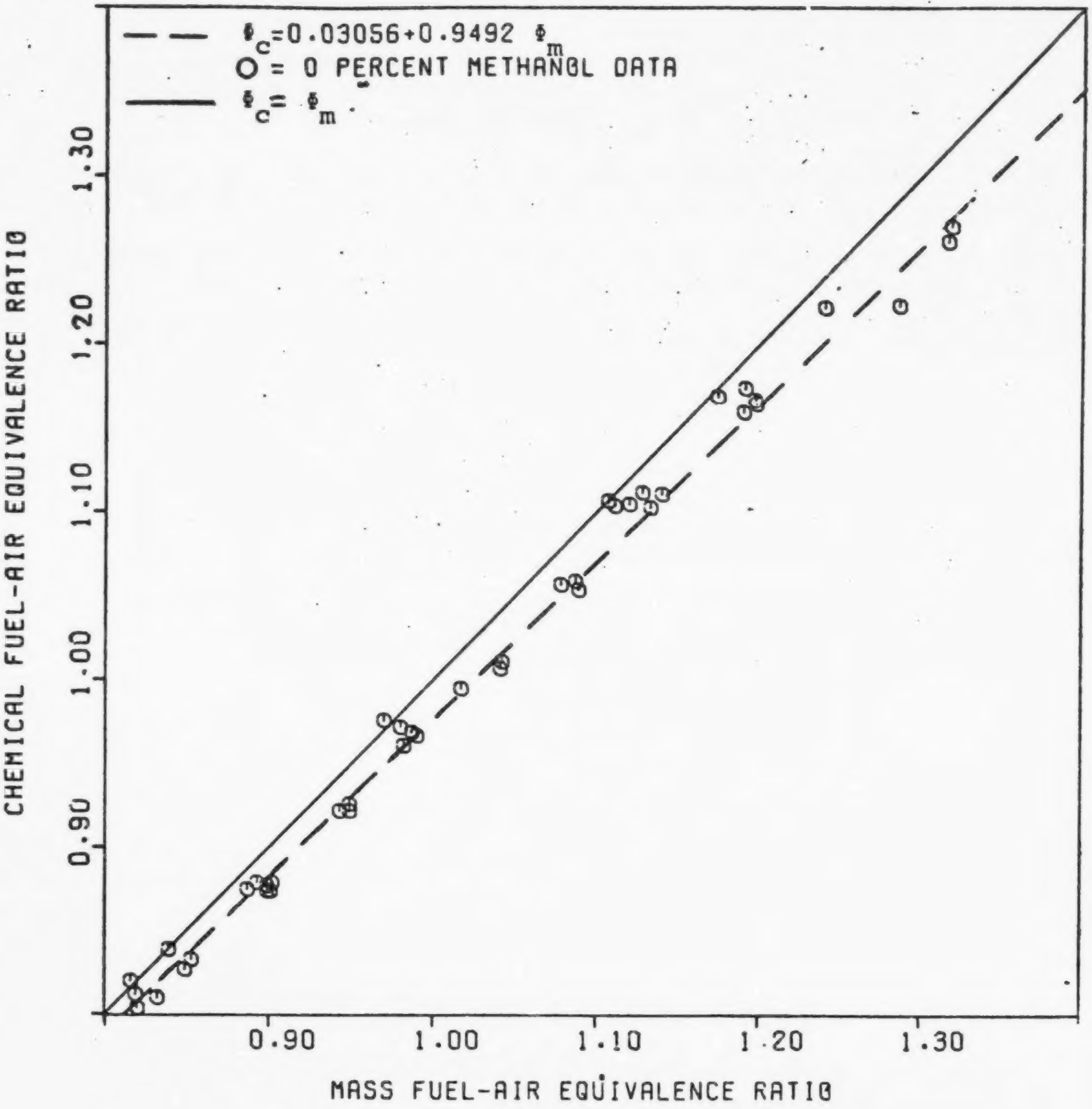


FIGURE 1 CHEMICAL VS. MASS FUEL-AIR EQUIVALENCE RATIO FOR INDOLENE FUEL. 2000 RPM. 16 IN. HG. MBT SPARK.

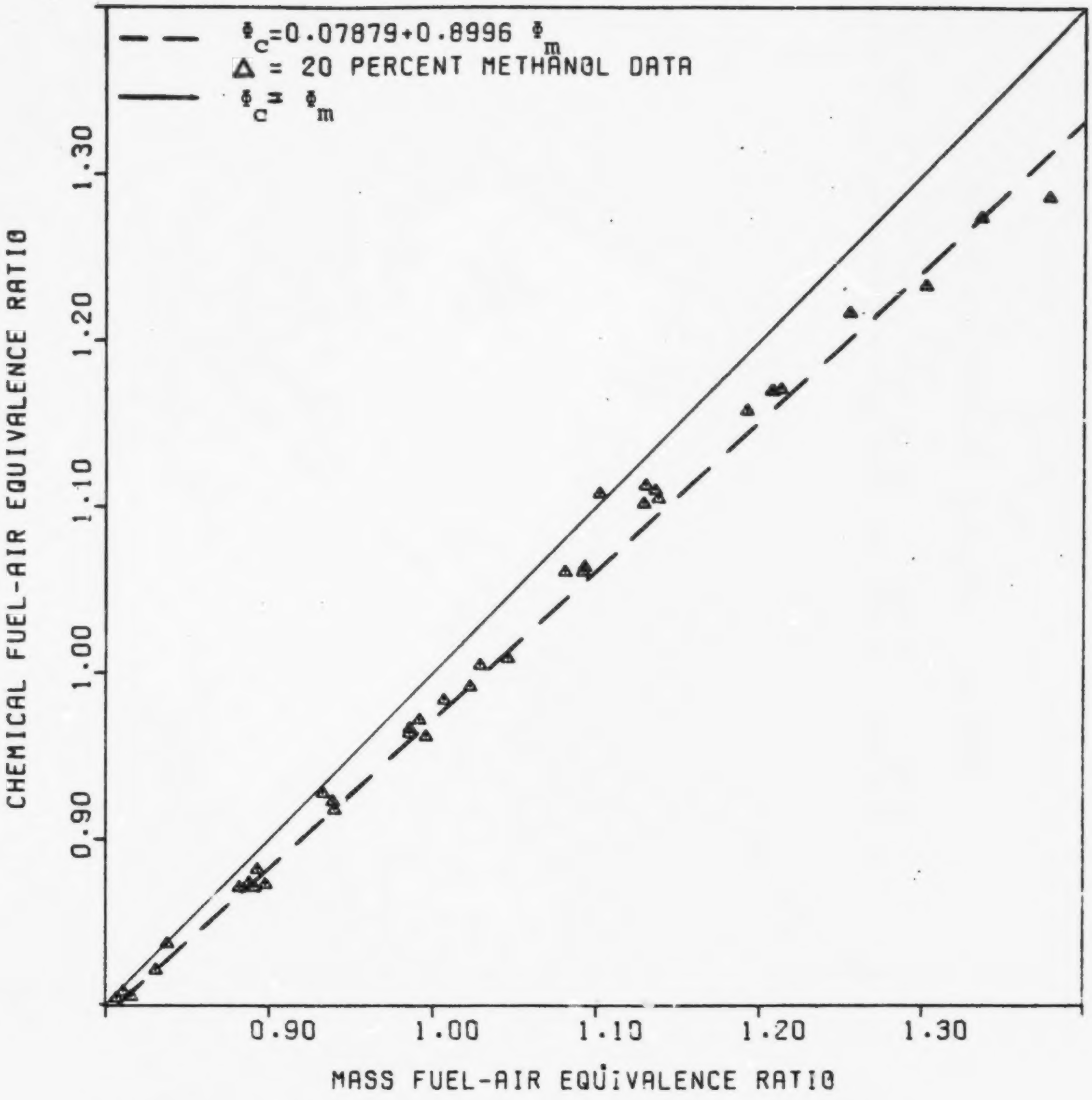


FIGURE 2 CHEMICAL VS. MASS FUEL-AIR EQUIVALENCE RATIO FOR 20 PERCENT METHANOL-INDOLENE BLEND FUEL.2000 RPM.16 IN.HG. MBT SPARK.

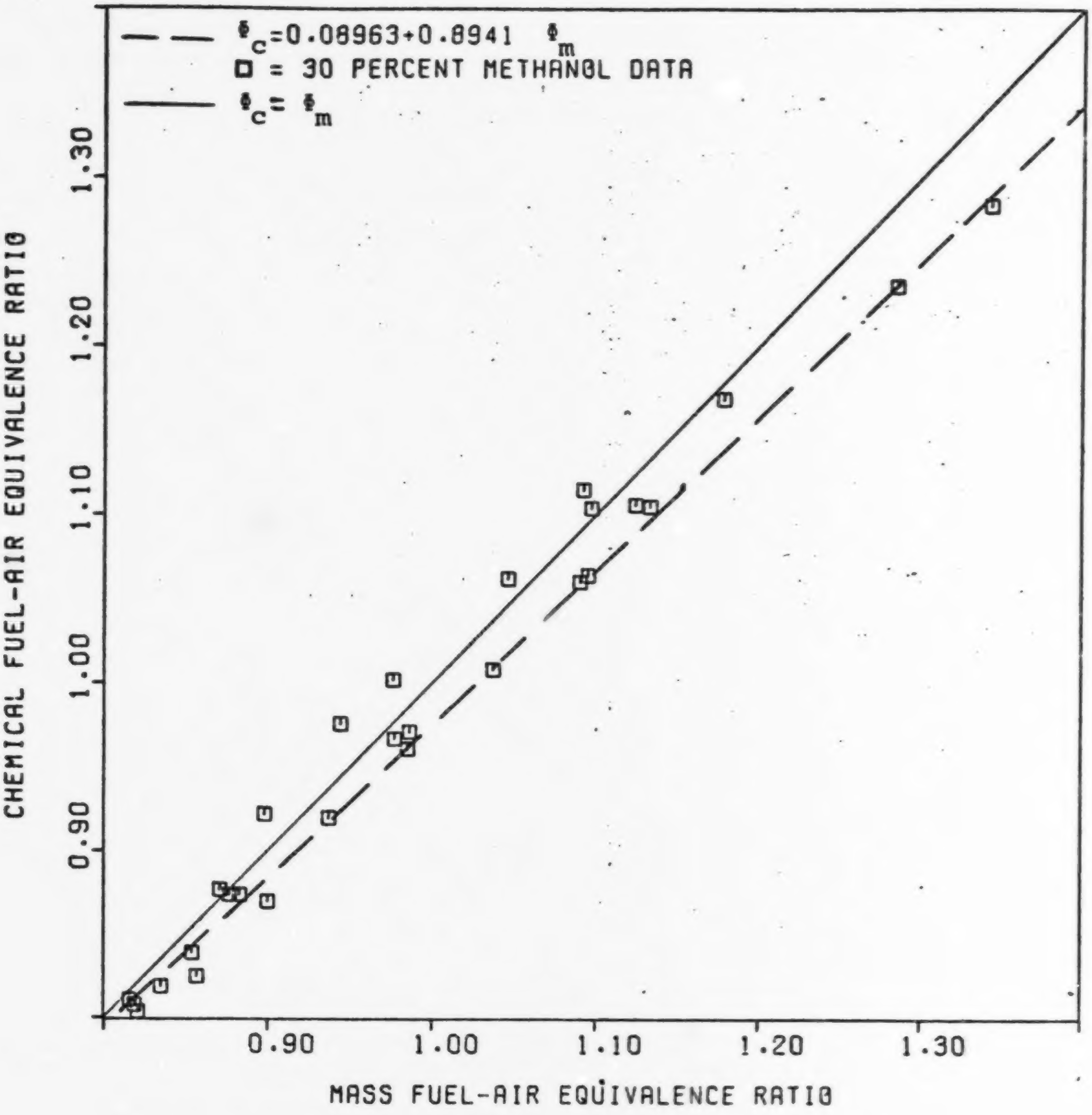


FIGURE 3 CHEMICAL VS. MASS FUEL-AIR EQUIVALENCE RATIO FOR 30 PERCENT METHANOL-INDOLENE BLEND FUEL.2000 RPM.16 IN. HG. MBT SPARK.

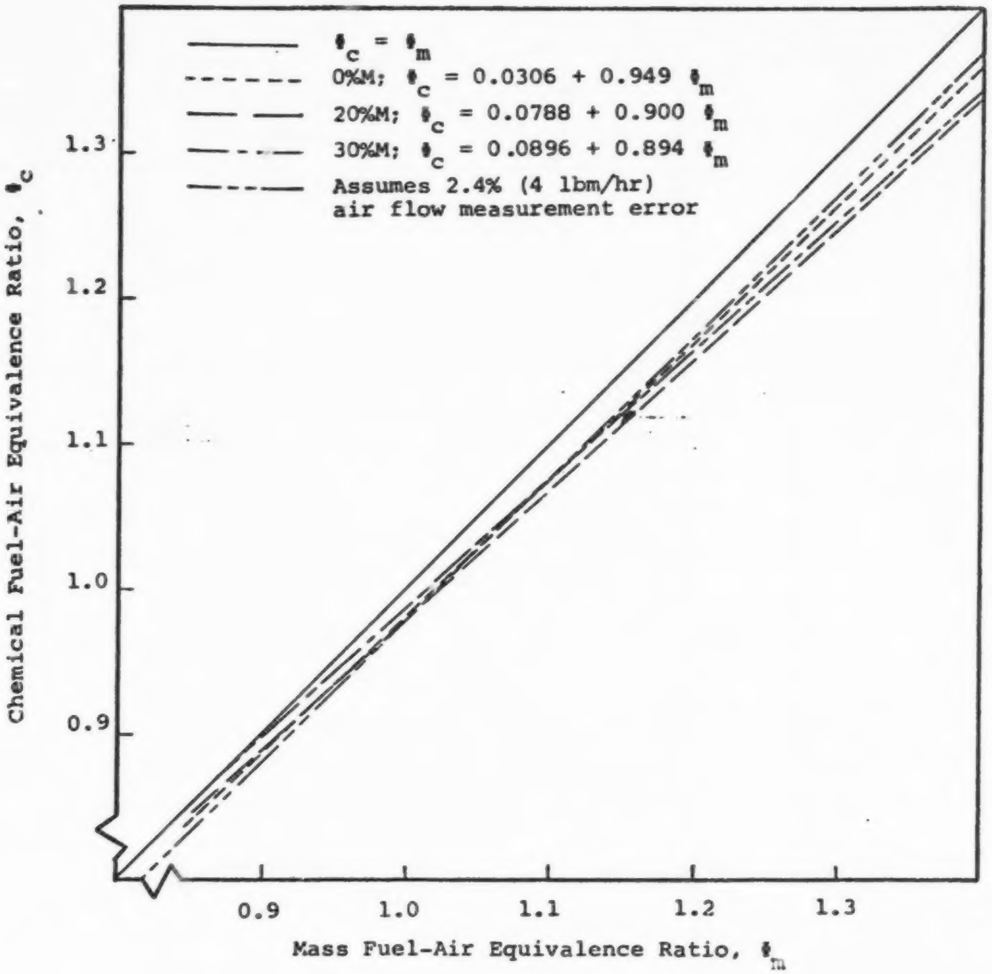


Figure 4 - Superimposes the ϕ_c versus ϕ_m Regression Analysis Curves for 0, 20 and 30%M Blends, 2000 RPM, 16 in. Hg, MBT Spark Advance

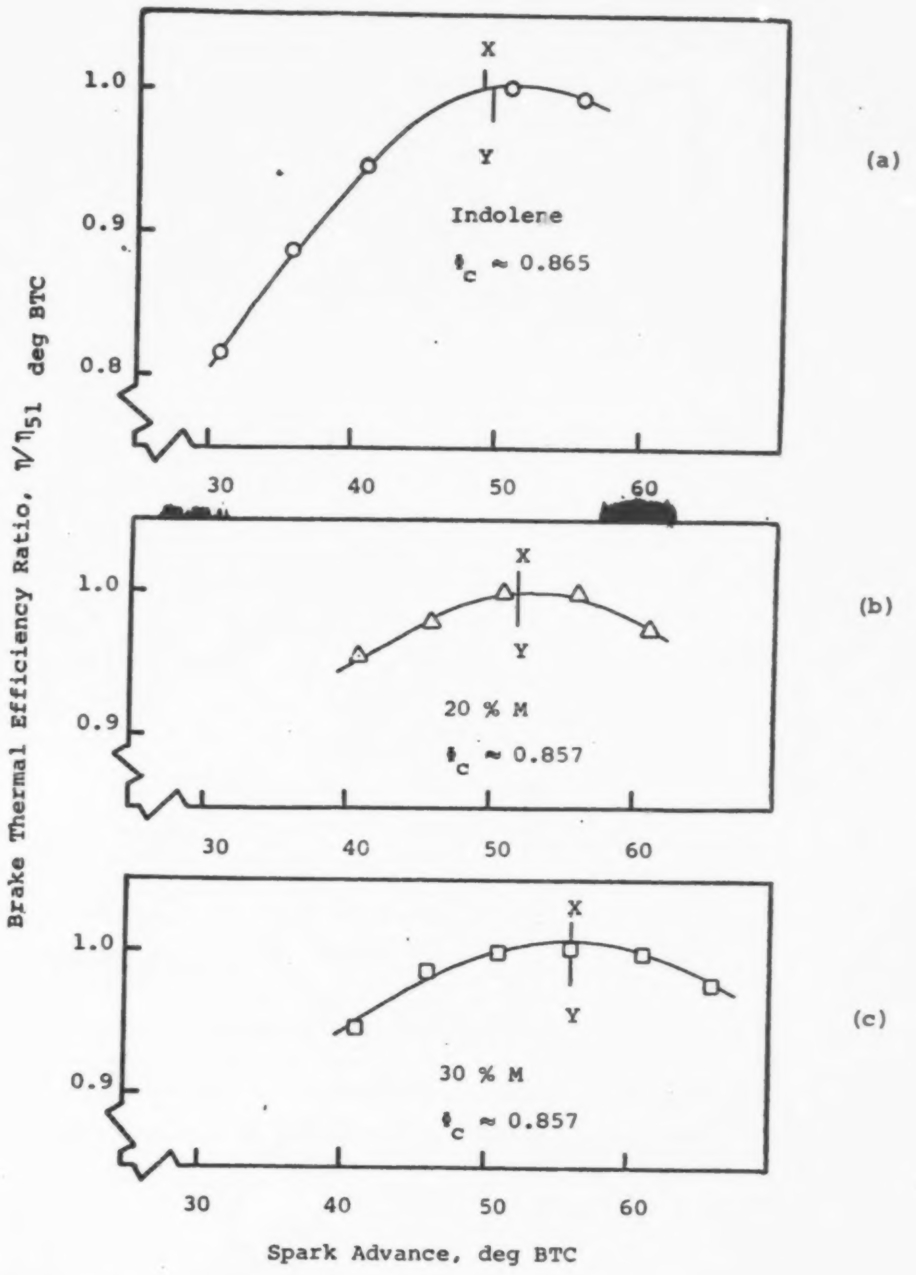


Figure 5 - Brake Thermal Efficiency versus Spark Advance

(2000 RPM and 16 in. Hg (54 kPa) manifold vacuum).

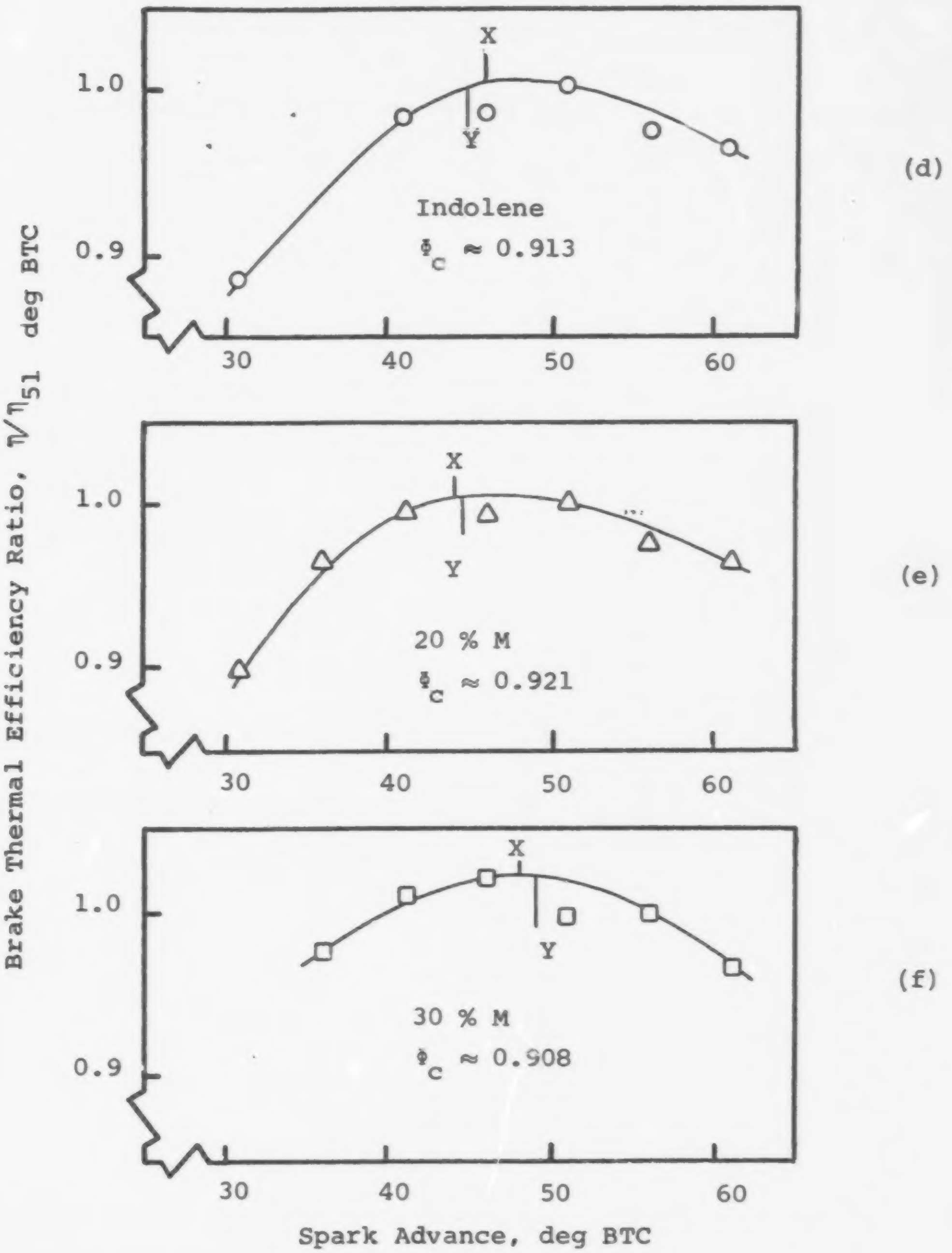


Figure 5 - Brake Thermal Efficiency versus Spark Advance (cont.)
(2000 RPM and 16 in Hg (54 kPa) manifold vacuum).

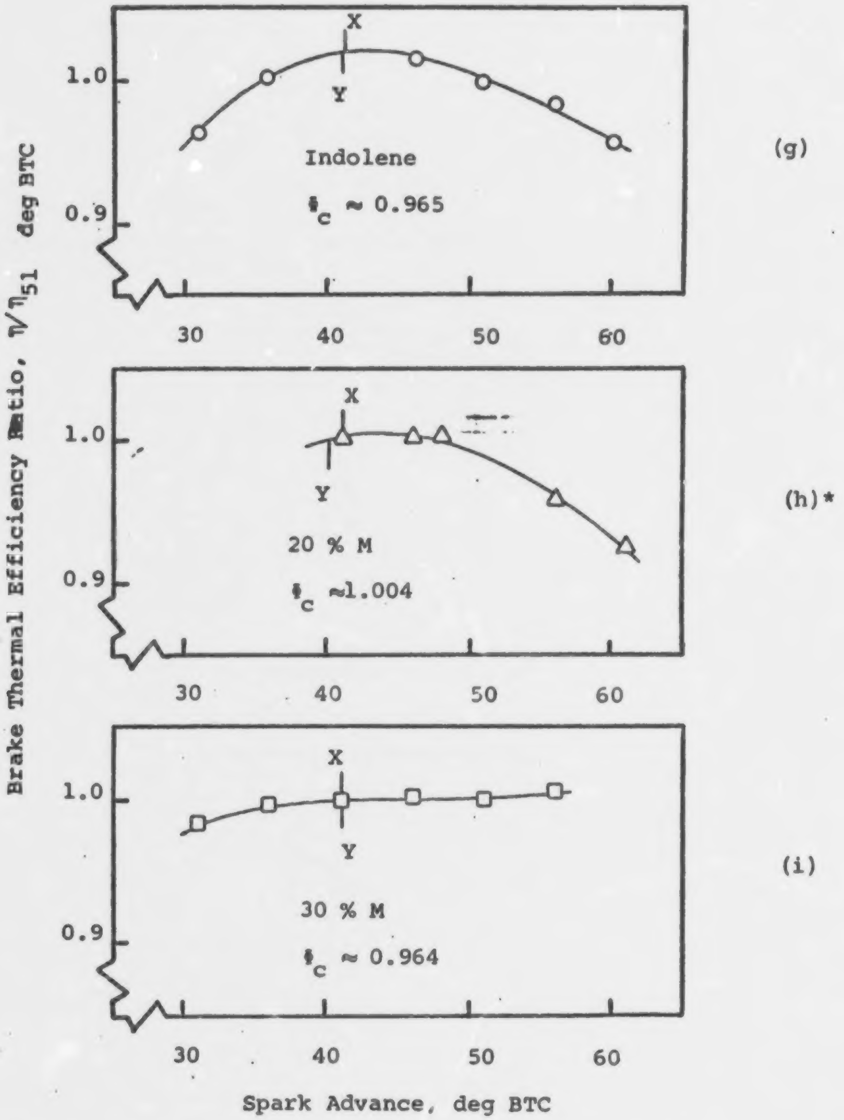


Figure 5 - Brake Thermal Efficiency versus Spark Advance (cont.) (2000 RPM and 16. in Hg (54 kPa) manifold vacuum).

* In Figure 24 (h) the efficiency ratio is η/η 48 deg BTC

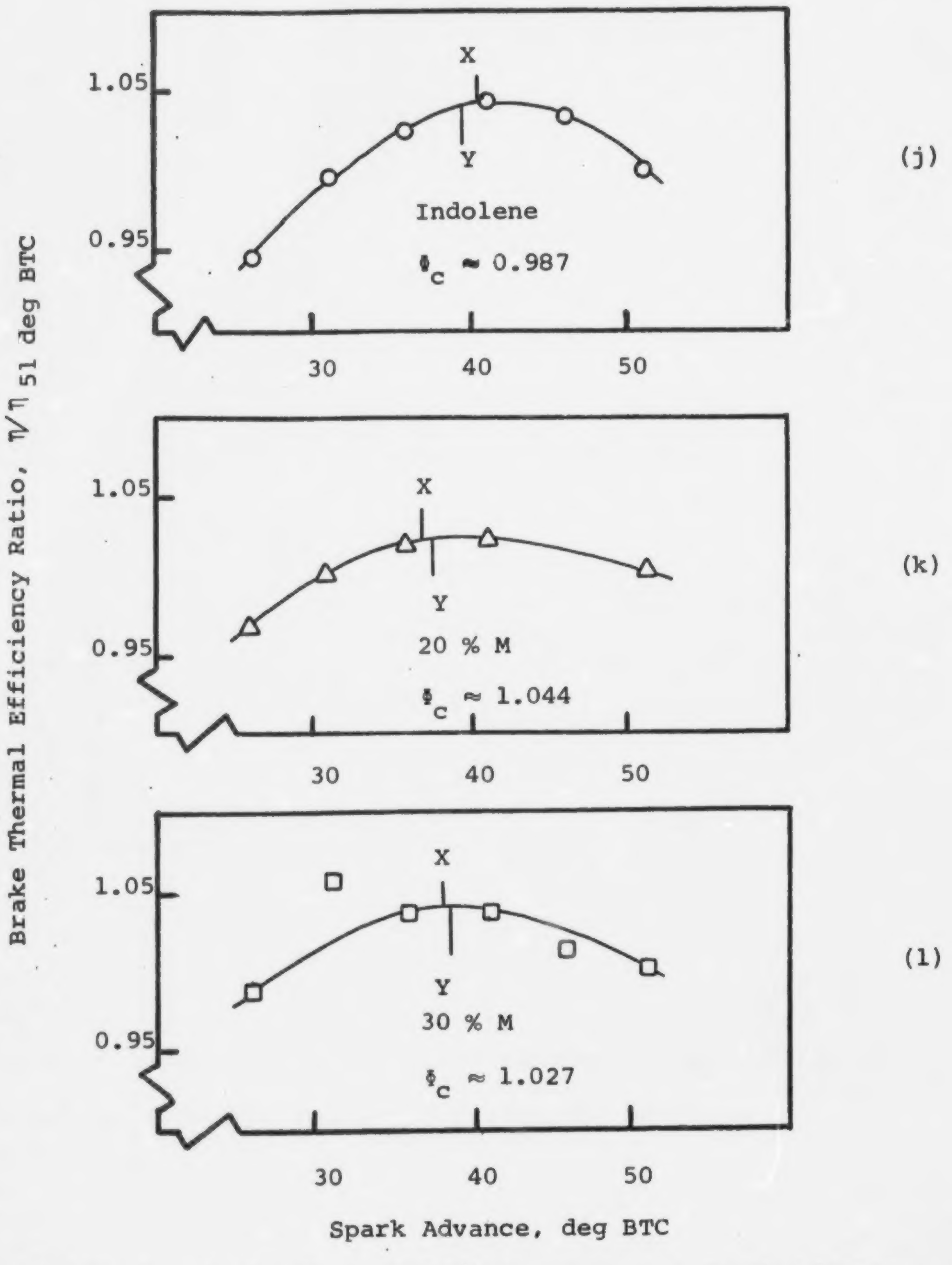
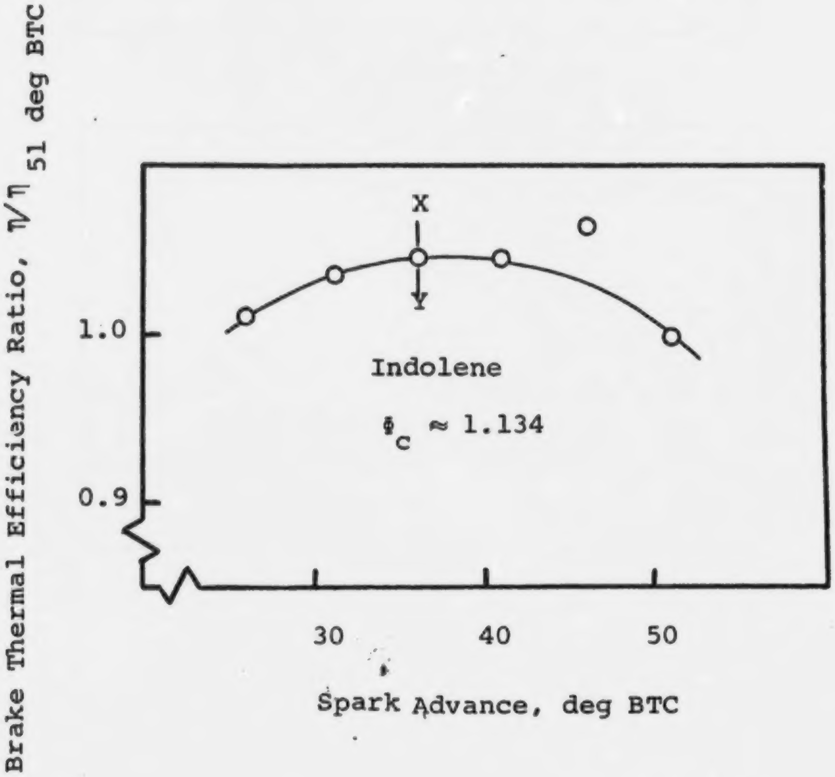


Figure 5 - Brake Thermal Efficiency versus Spark Advance (cont.)
(2000 RPM and 16 in. Hg (54 kPa) manifold vacuum).



(m)

Figure 5 (cont.) - Brake Thermal Efficiency versus Spark Advance (2000 RPM and 16 in. Hg (54 kPa) manifold vacuum).

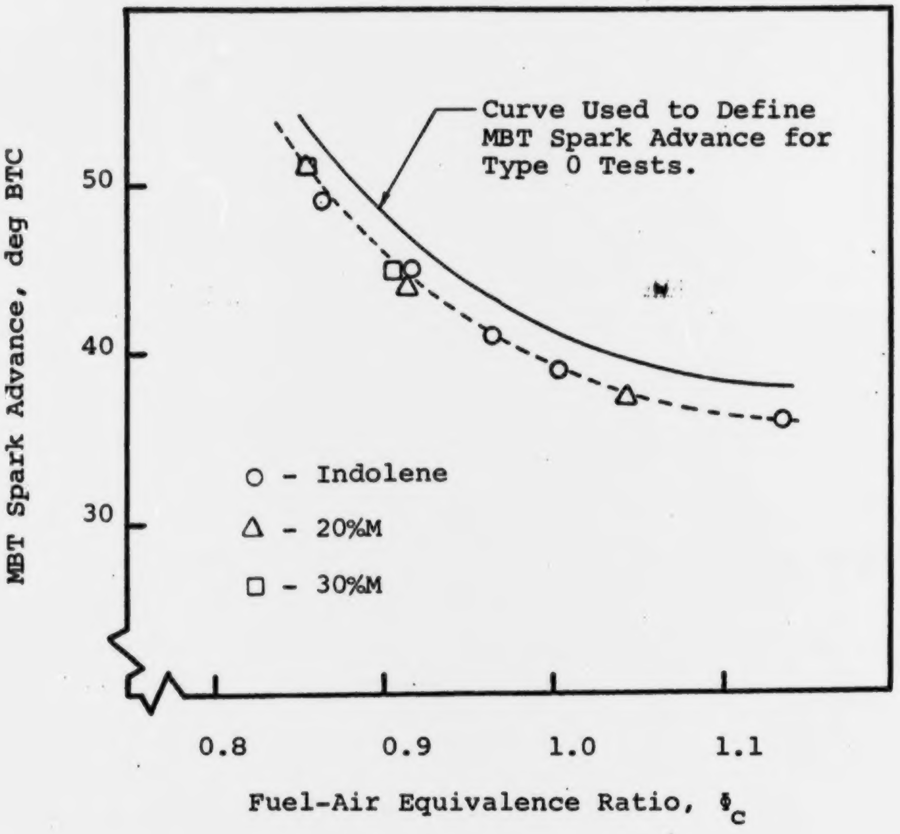


Figure 6 - MBT Spark Advance versus Equivalence Ratio, Φ_c, for 0, 20 and 30%M Blends at 2000 RPM and 16 in. Hg (54 kPa) manifold vacuum.

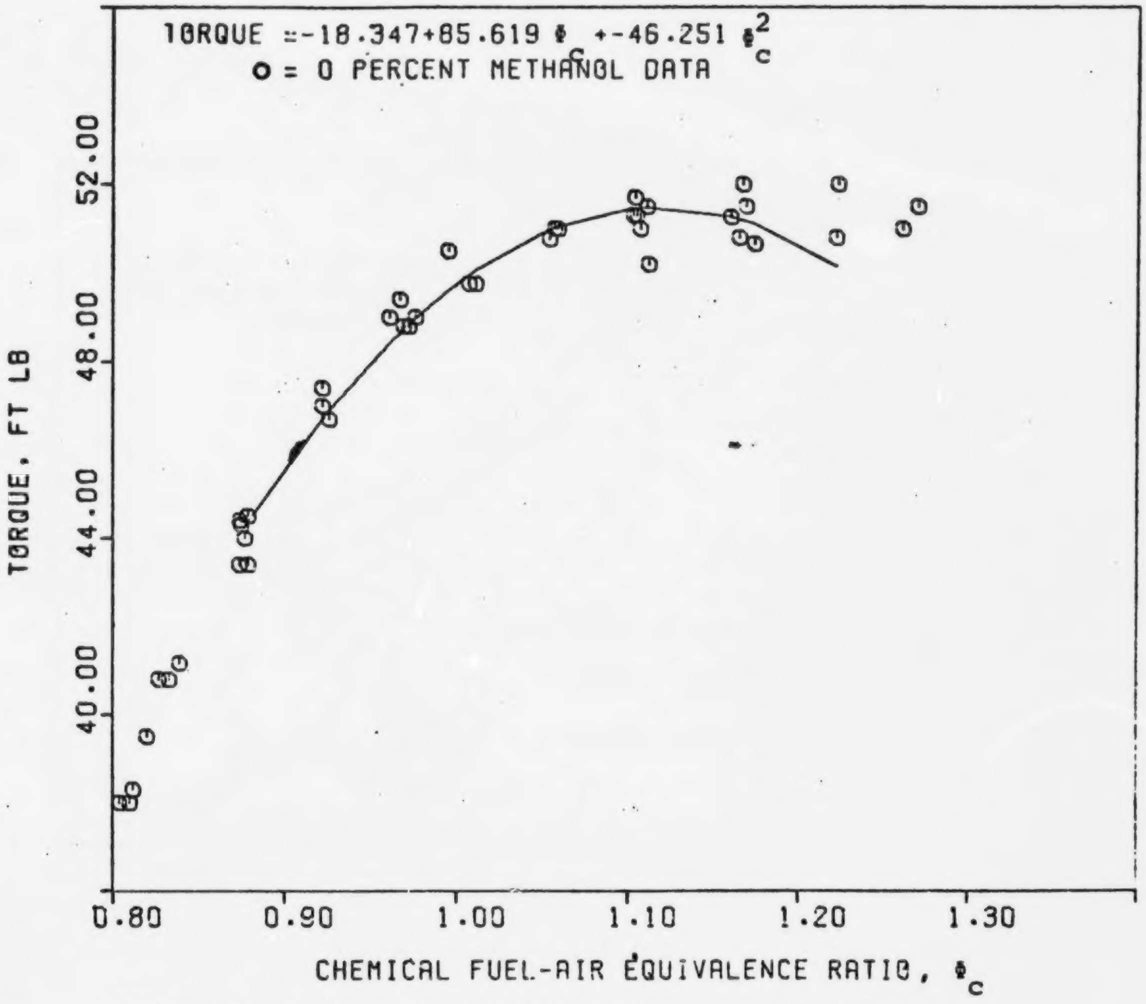


FIGURE 7 TORQUE VS. CHEMICAL FUEL-AIR EQUIVALENCE RATIO FOR INDOLENE FUEL.2000 RPM.16 IN.HG.MBT SPARK.

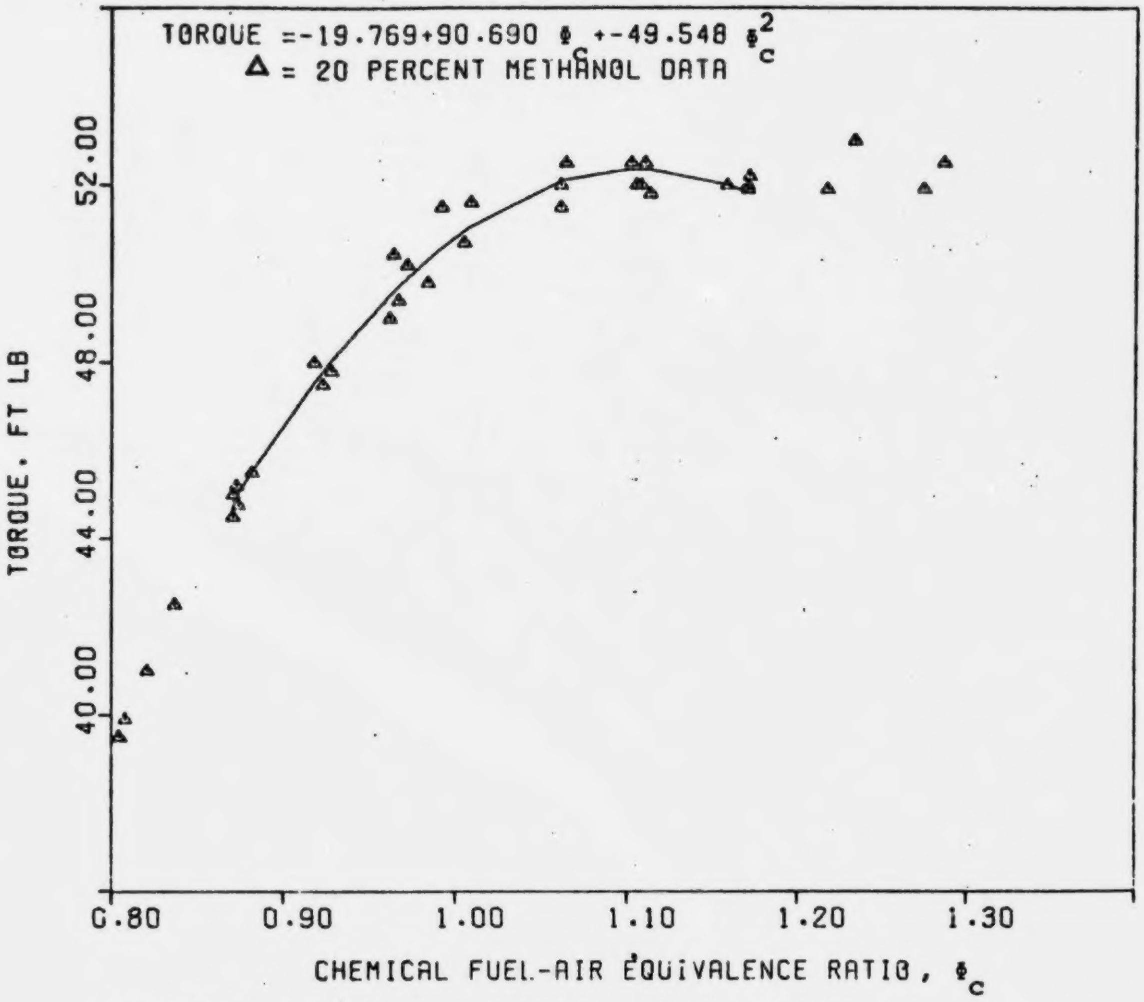


FIGURE 8 TORQUE VS. CHEMICAL FUEL-AIR EQUIVALENCE RATIO FOR 20 PERCENT METHANOL-INDOLENE BLEND FUEL, 2000 RPM, 16 IN. HG, MBT SPARK.

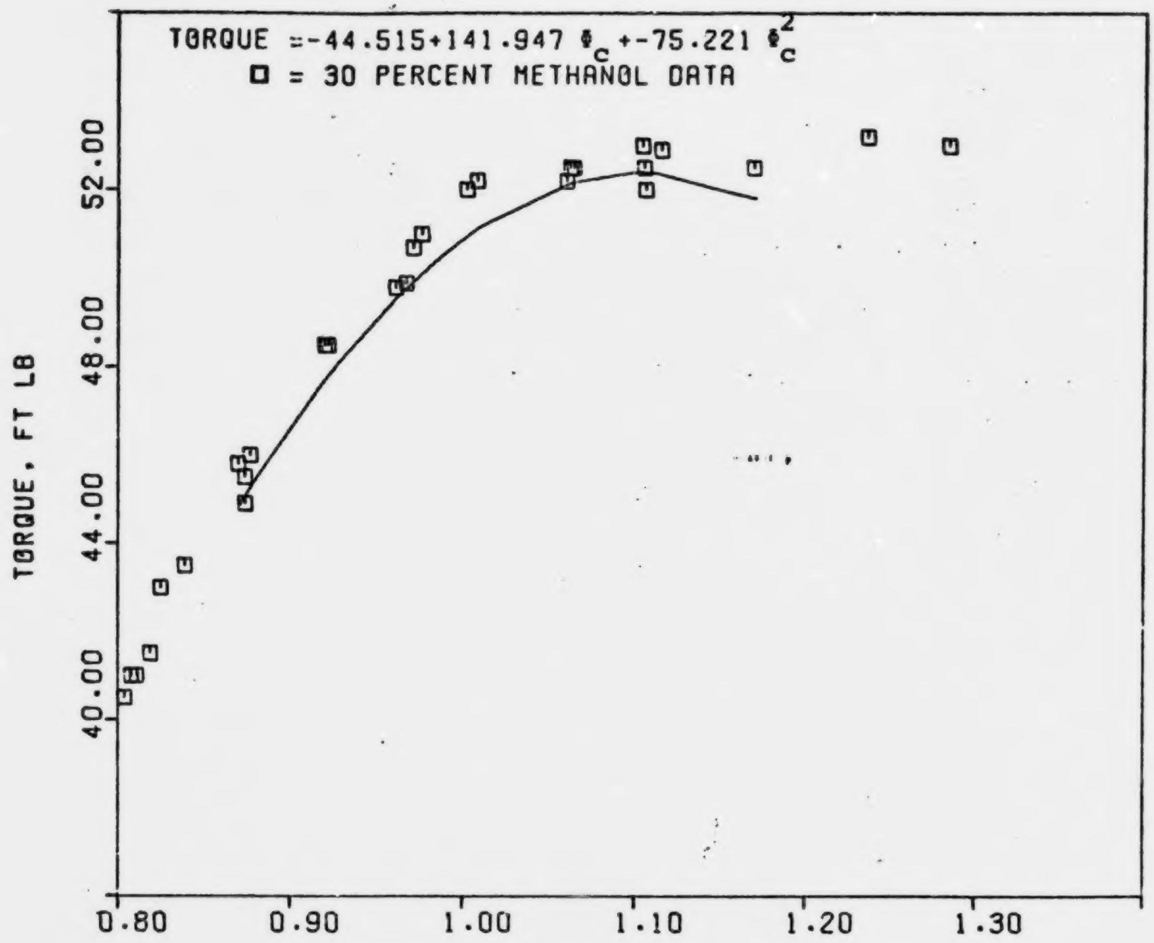


FIGURE 9 TORQUE VS. CHEMICAL FUEL-AIR EQUIVALENCE RATIO FOR 30 PERCENT METHANOL-INDOLENE BLEND FUEL.2000 RPM.16 IN. HG.MBT SPARK.

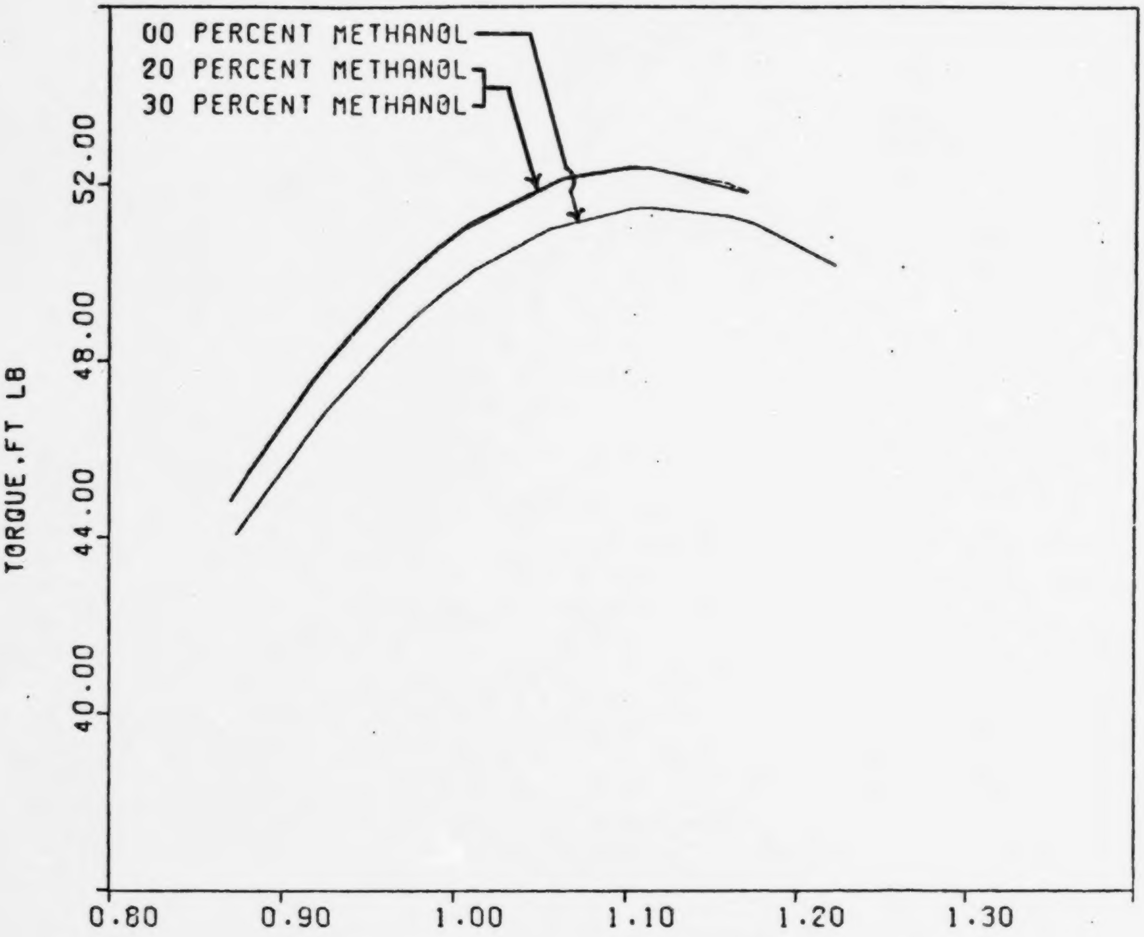


FIGURE 10 EQUATION (1) REGRESSION MODEL CURVES FOR TORQUE VS. CHEMICAL FUEL-AIR EQUIVALENCE RATIO .2000 RPM.16 IN.HG MBT SPARK.

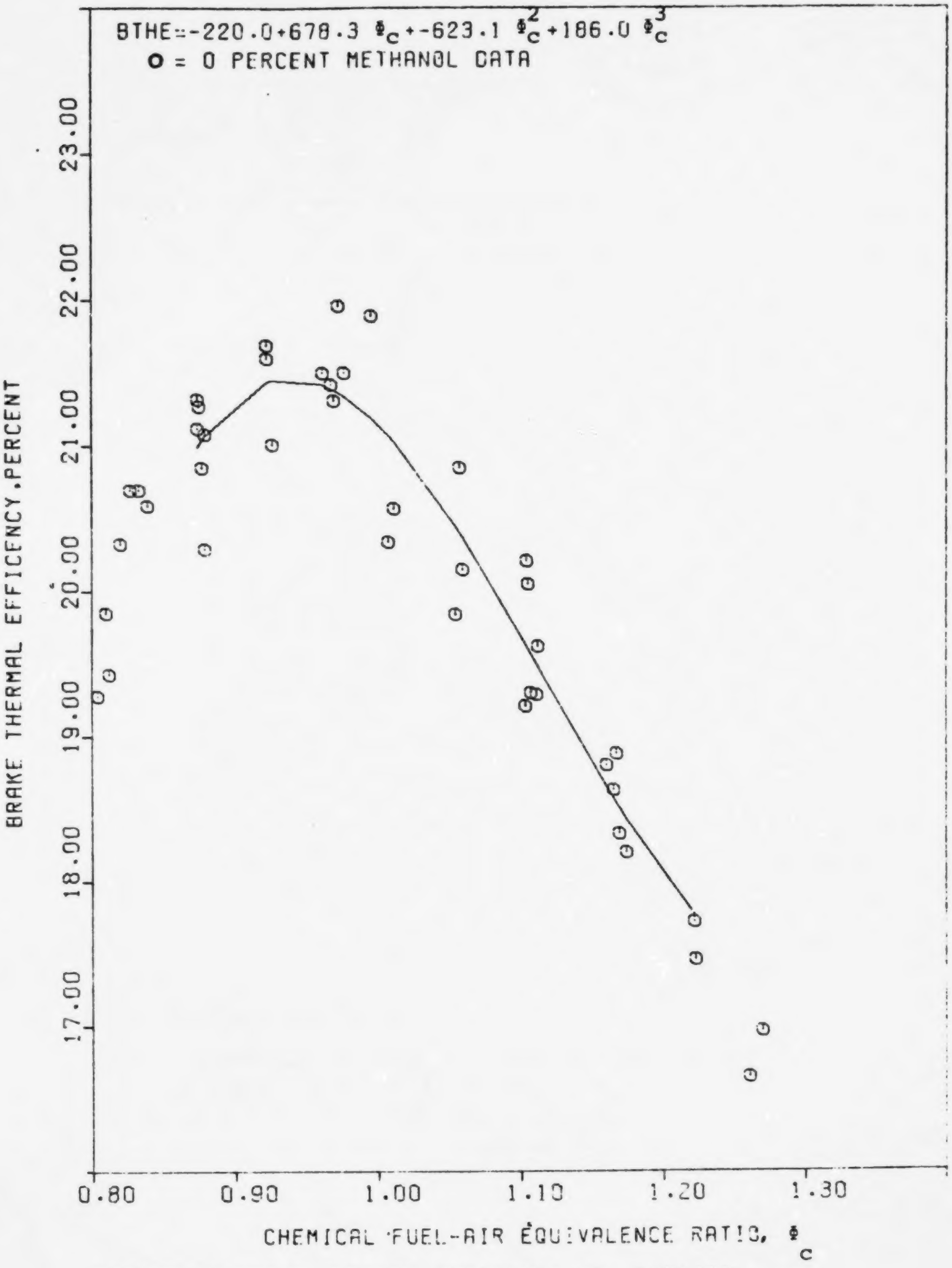


FIGURE **11** BRAKE THERMAL EFFICENCY VS. CHEMICAL FUEL-AIR EQUIVALENCE RATIO FOR INDOLENE FUEL,2000 RPM,16 IN.HG,MBT SPARK.

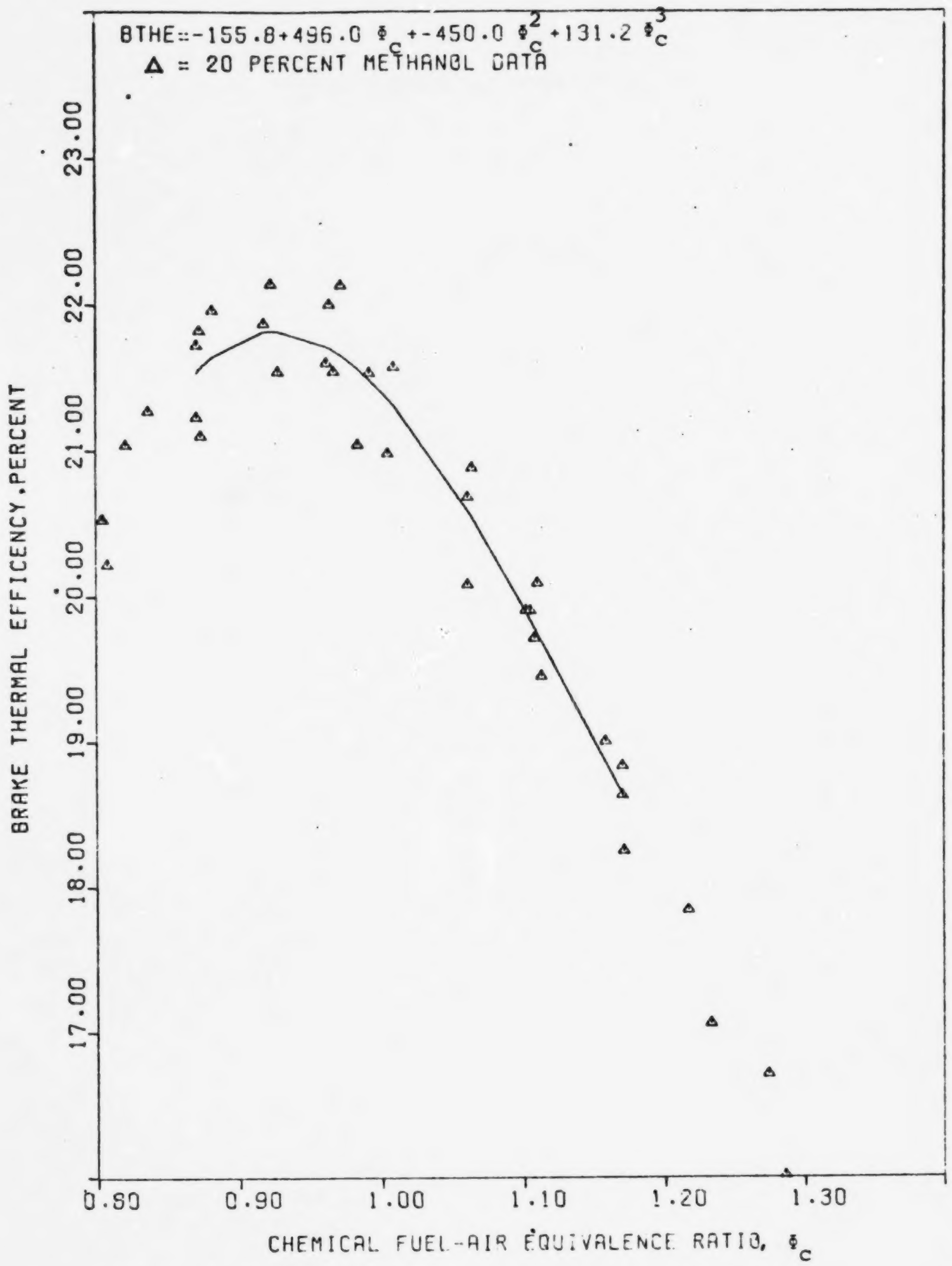


FIGURE 12 BRAKE THERMAL EFFICENCY VS. CHEMICAL FUEL-AIR EQUIVALENCE RATIO FOR 20 PERCENT METHANOL-INDOLENE BLEND FUEL .2000 RPM.16 IN.HG.MBT SPARK.

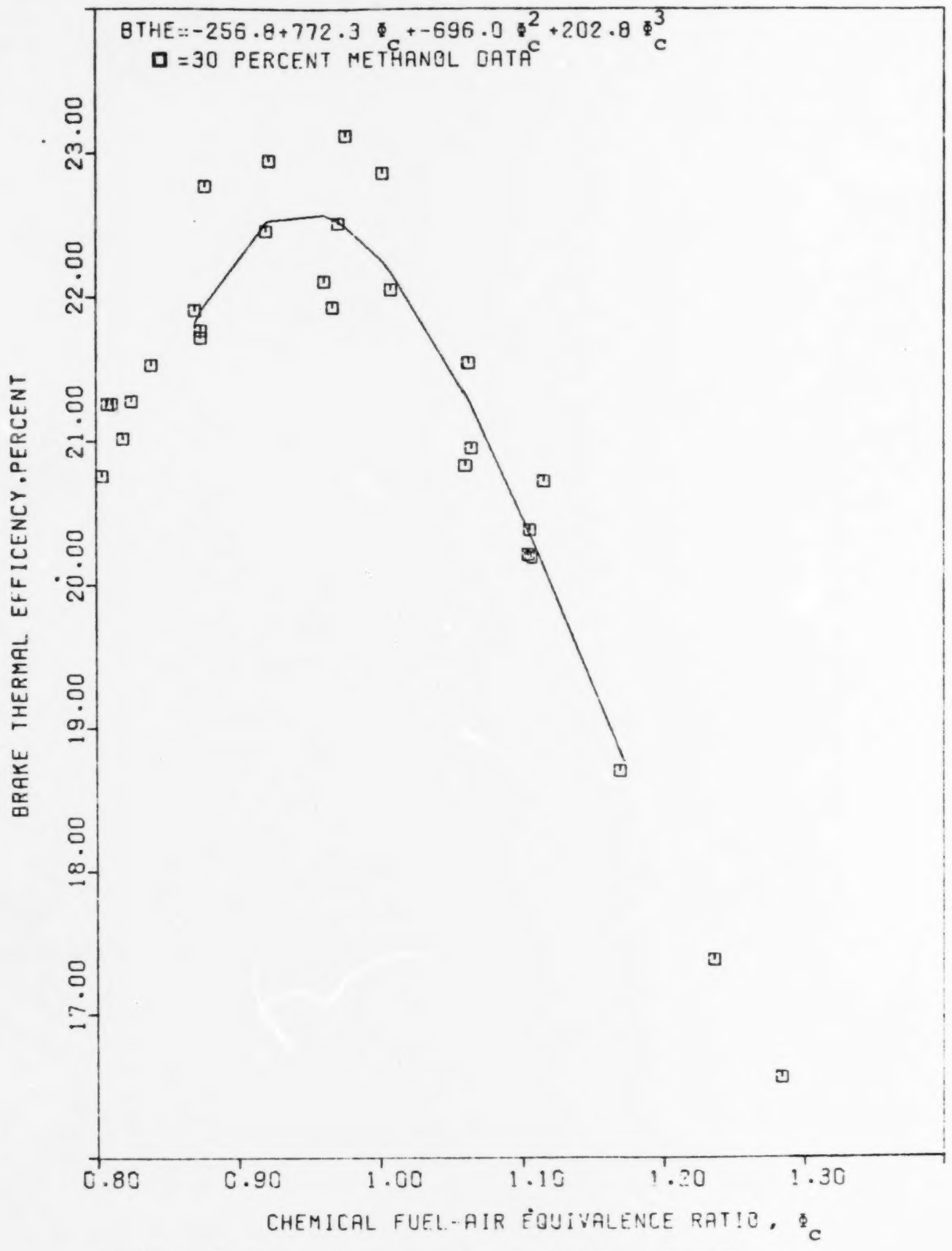


FIGURE 13 BRAKE THERMAL EFFICENCY VS. CHEMICAL FUEL-AIR EQUIVALENCE RATIO FOR 30 PERCENT METHANOL-INDOLENE BLEND FUEL .2000 RPM.16 IN.HG.MBT SPARK.

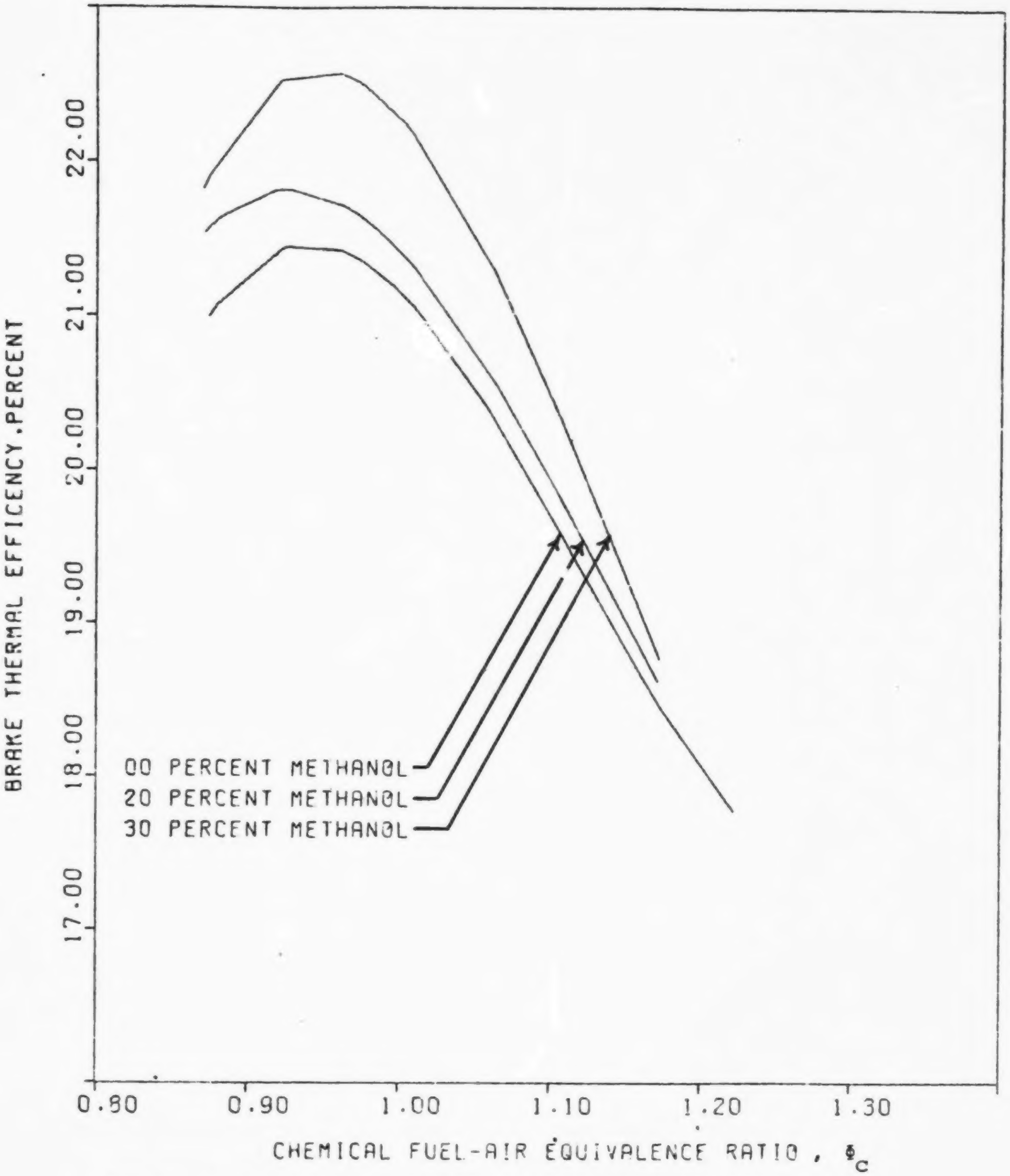


FIGURE 14 EQUATION (1) REGRESSION MODEL CURVES FOR BRAKE THERMAL EFFICENCY VS. CHEMICAL FUEL-AIR EQUIVALENCE RATIO .2000 RPM.16 IN.HG.MBT SPARK.

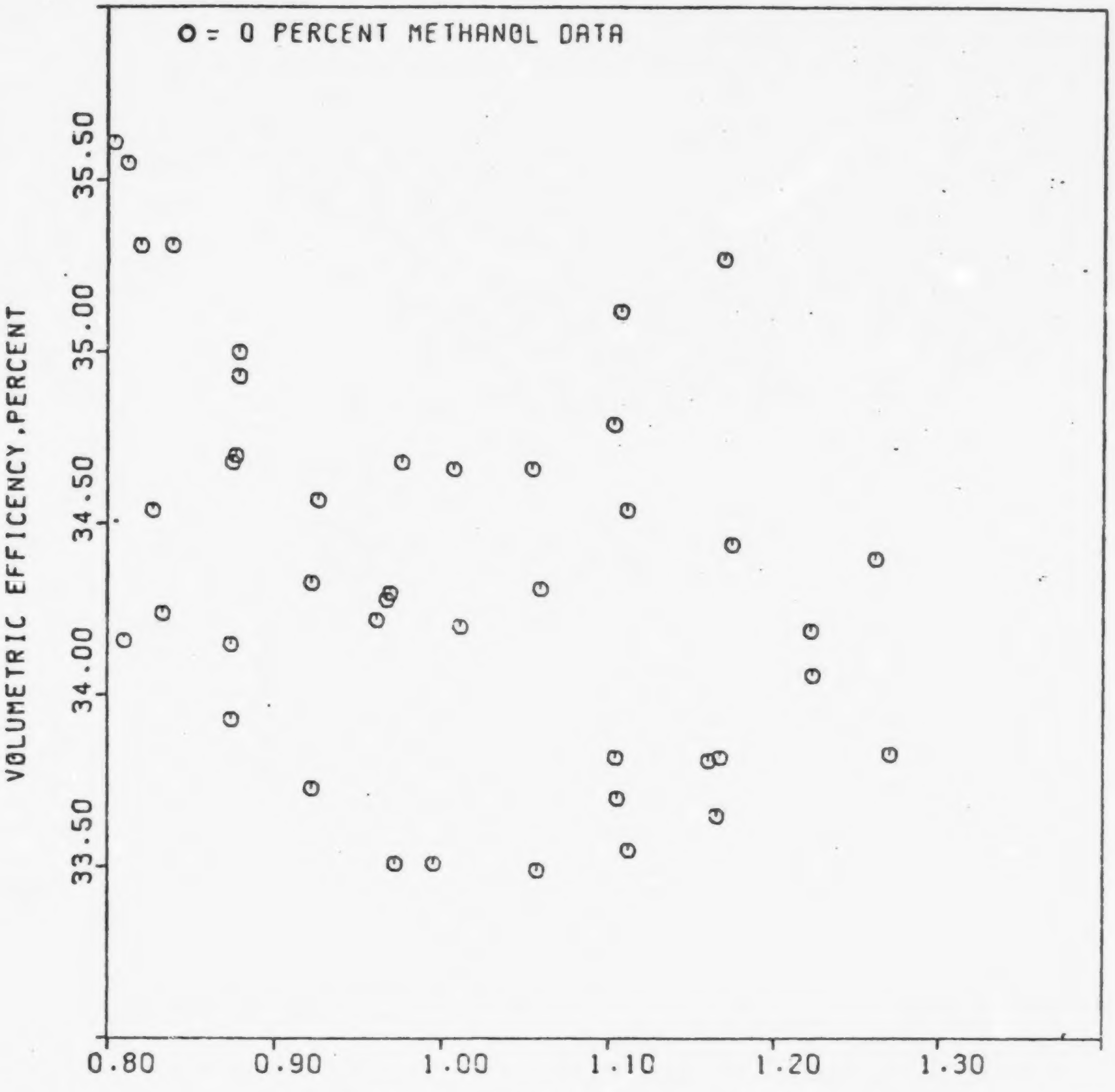


FIGURE 15 VOLUMETRIC EFFICENCY VS. CHEMICAL FUEL -AIR EQUIVALENCE RATIO FOR INDOLENE FUEL,2000 RPM,16. IN HG,MBT SPARK.

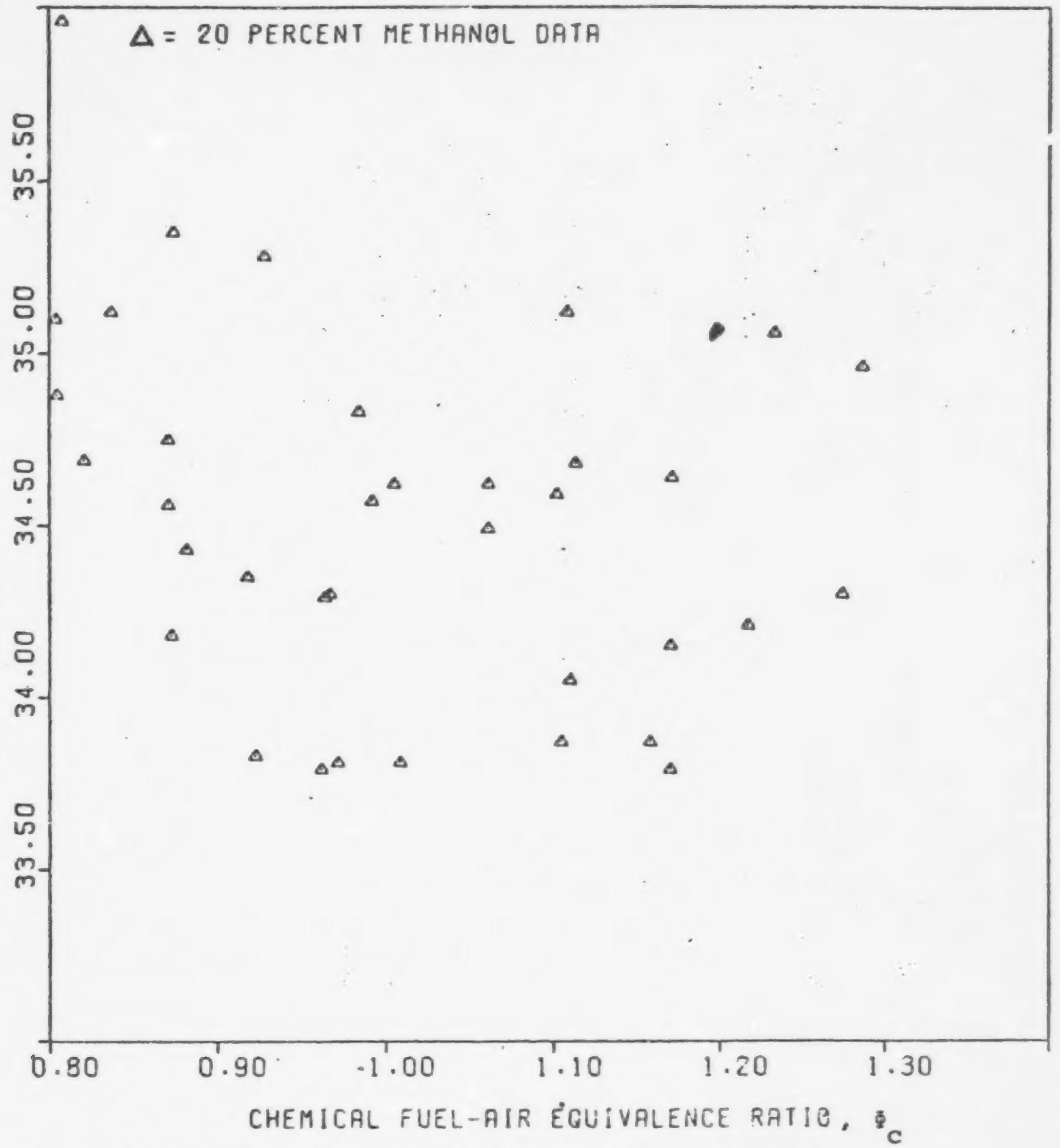


FIGURE 16 VOLUMETRIC EFFICENCY VS. CHEMICAL FUEL -AIR EQUIVALENCE RATIO FOR 20 PERCENT METHANOL-INDOLENE BLEND FUEL. 2000 RPM, 16 IN. HG, MBT SPARK.

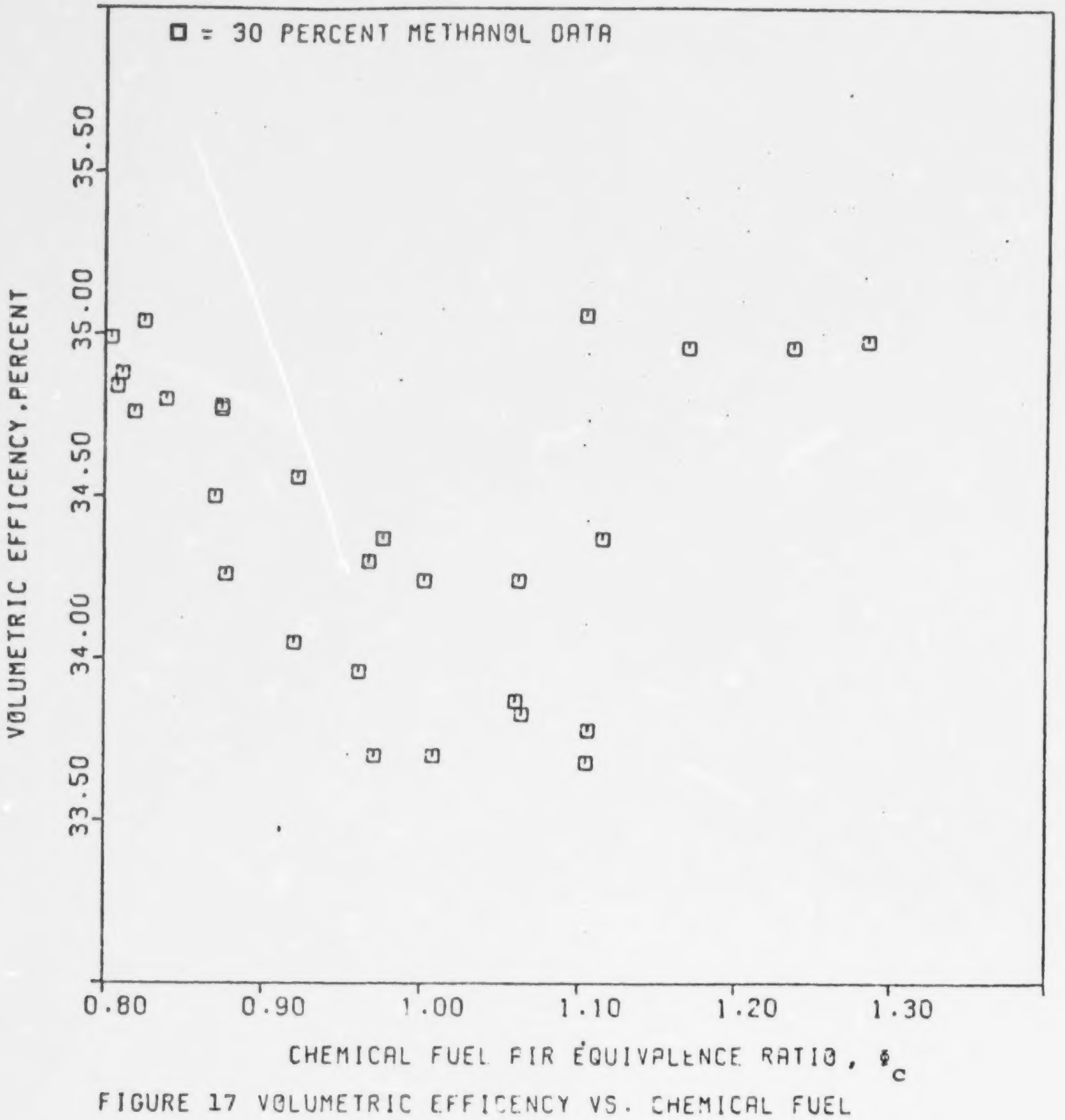


FIGURE 17 VOLUMETRIC EFFICENCY VS. CHEMICAL FUEL -AIR EQUIVALENCE RATIO FOR 30 PERCENT METHANOL-INDOLENE BLEND FUEL. 2000 RPM. 16 IN. HG. MBT SPARK.

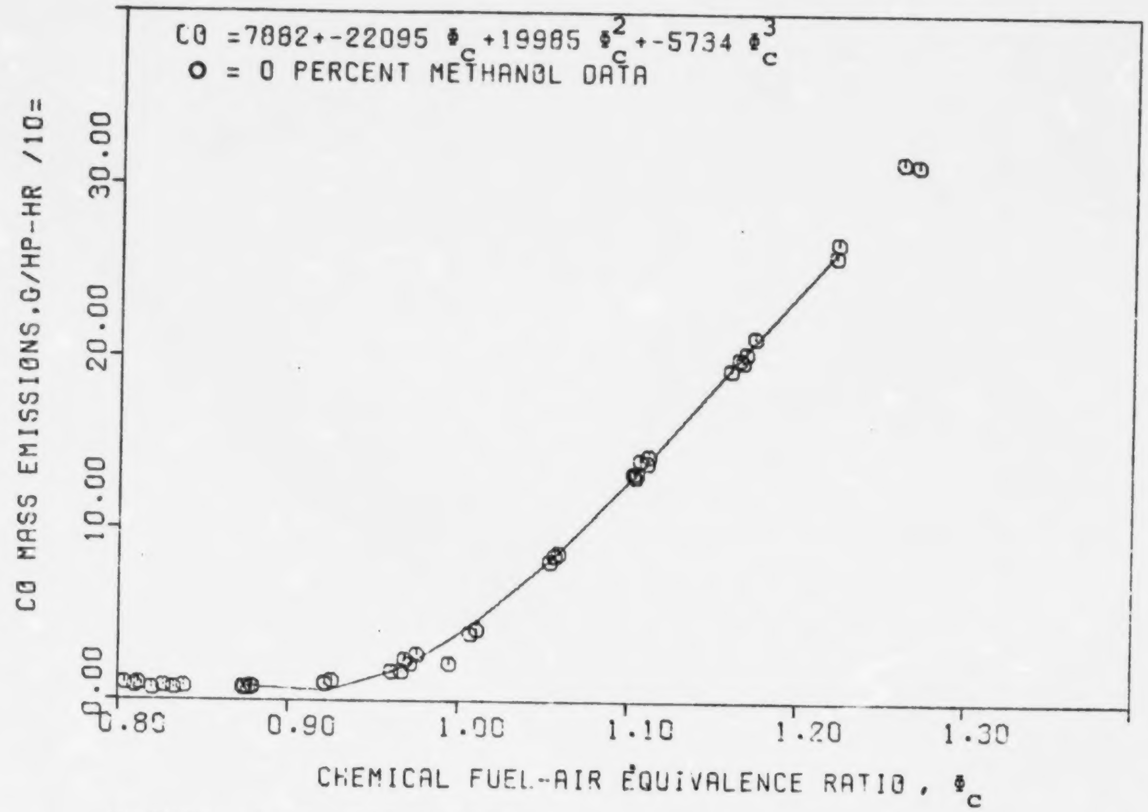


FIGURE 18 CO MASS EMISSIONS VS. CHEMICAL FUEL-AIR EQUIVALENCE RATIO FOR INDOLENE FUEL,2000 RPM,16 IN.HG,MBT SPARK.

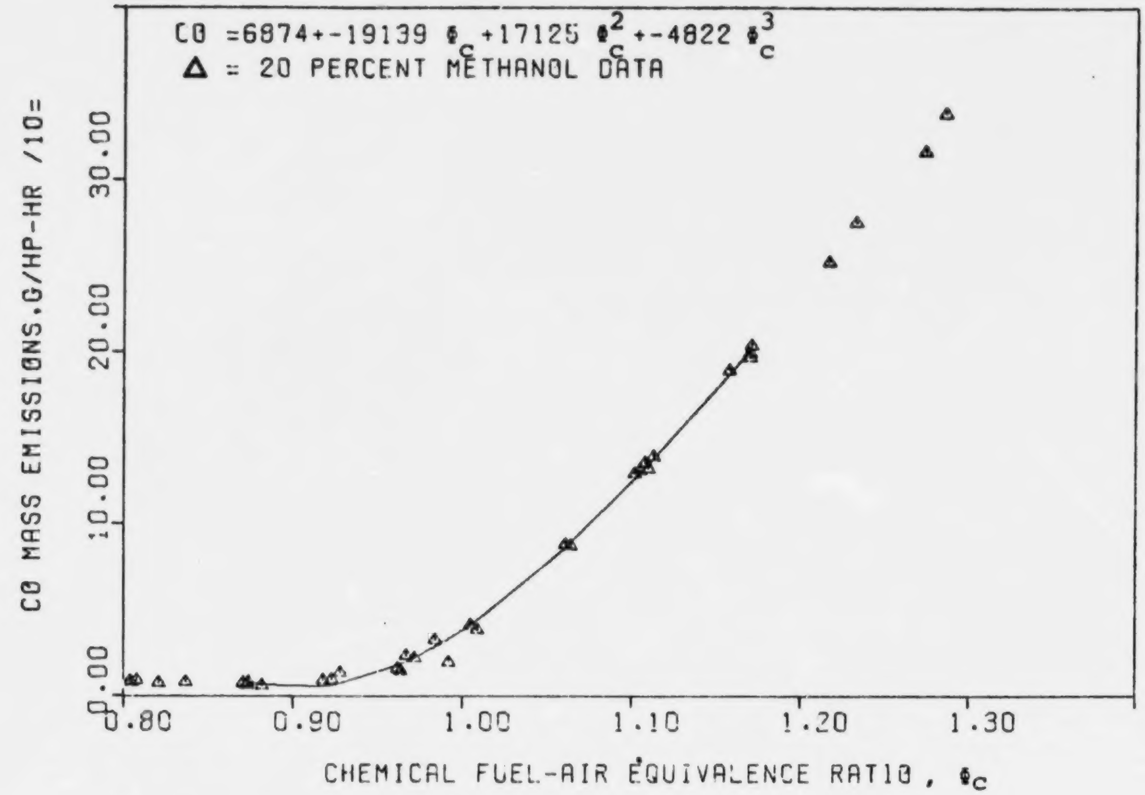


FIGURE 19 CO MASS EMISSIONS VS. CHEMICAL FUEL-AIR EQUIVALENCE RATIO FOR 20 PERCENT METHANOL-INDOLENE BLEND FUEL.2000 RPM.16 IN. HG.MBT SPARK.

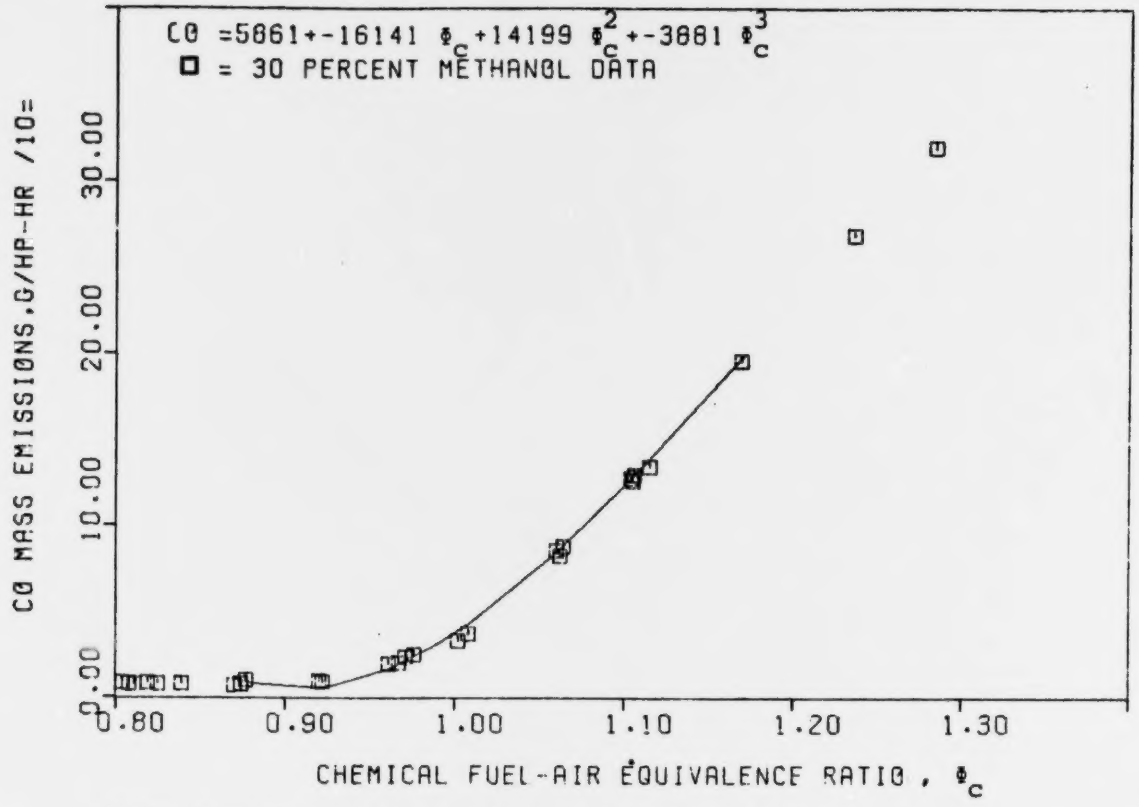


FIGURE 20 CO MASS EMISSIONS VS. CHEMICAL FUEL-AIR EQUIVALENCE RATIO FOR 30 PERCENT METHANOL-INDOLENE BLEND FUEL.2000 RPM.16 IN.HG.MBT SPARK.

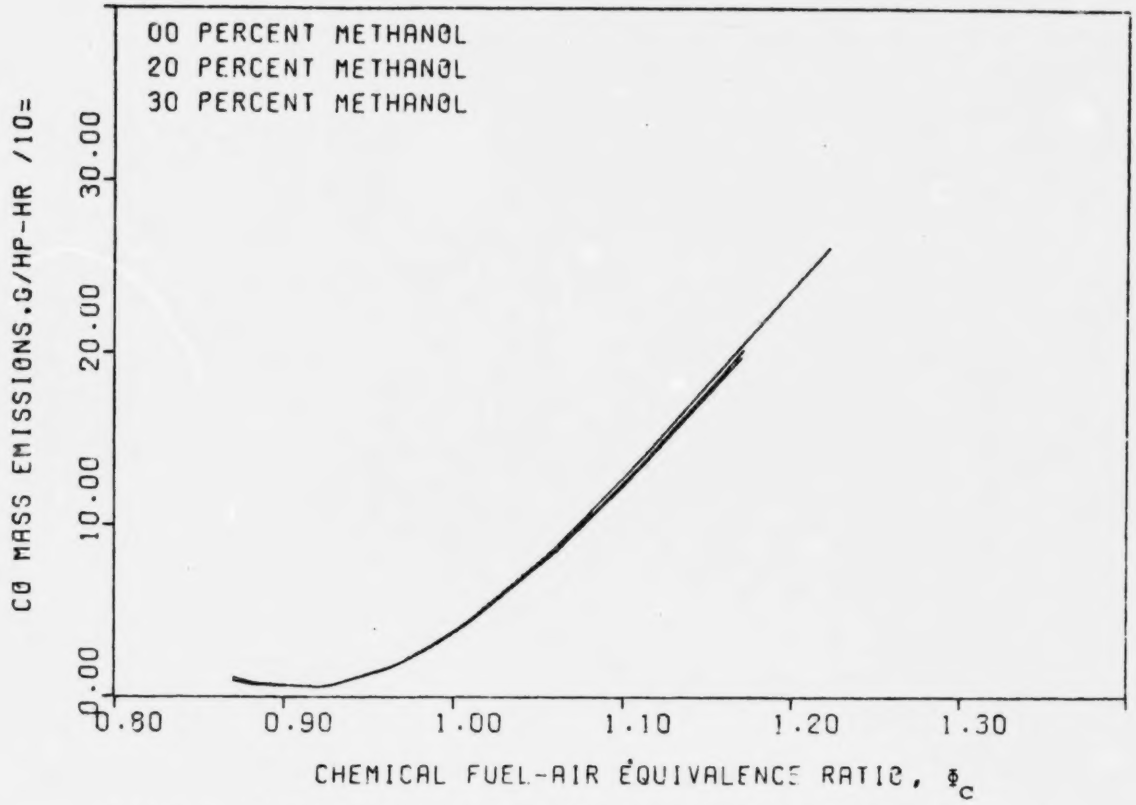


FIGURE 21 EQUATION (1) REGRESSION MODEL CURVES FOR CO MASS EMISSIONS VS. CHEMICAL FUEL-AIR EQUIVALENCE RATIO.2000 RPM. 16 IN. HG.MBT SPARK.

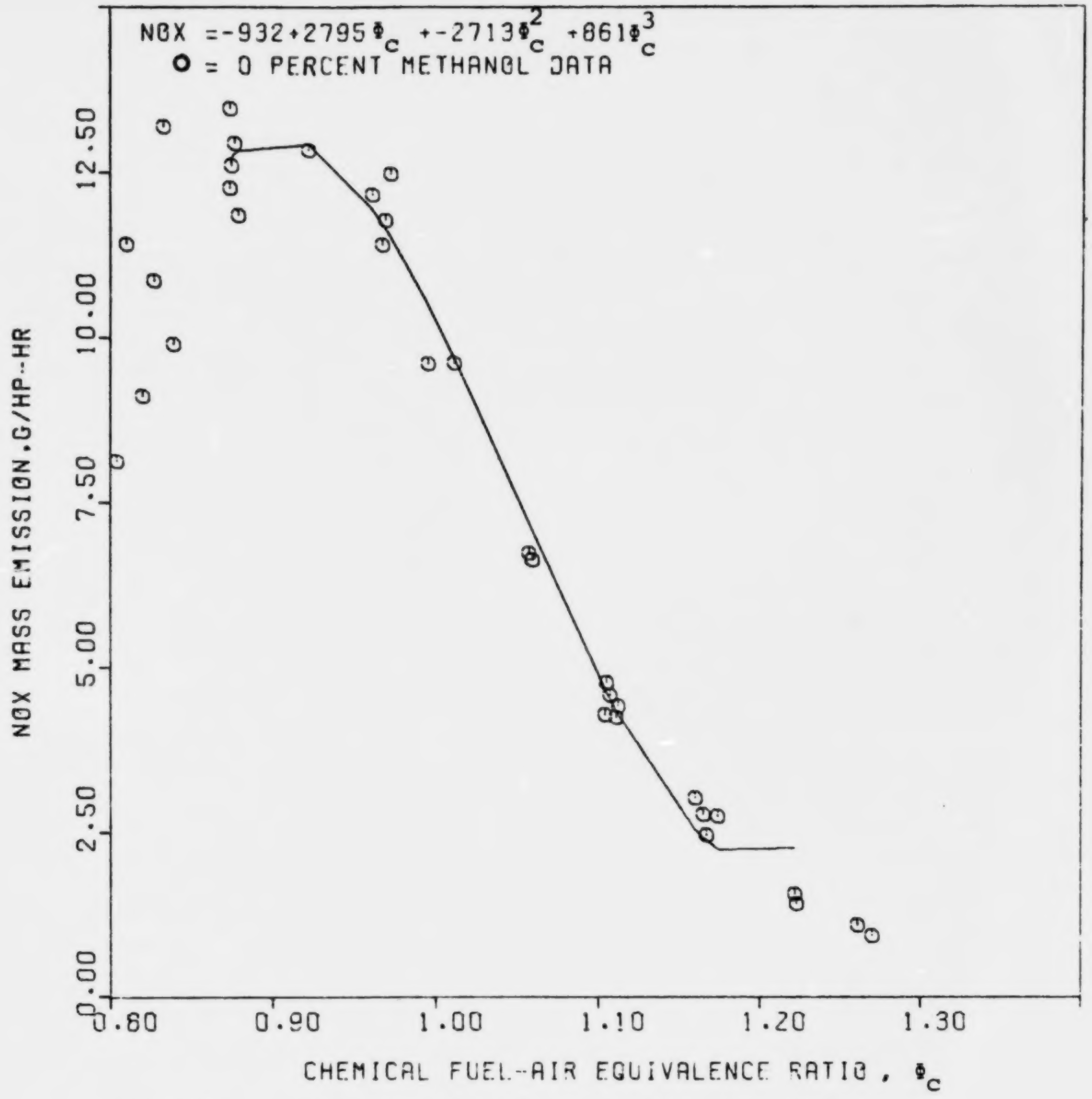


FIGURE 22 NOX MASS EMISSIONS VS. CHEMICAL FUEL-AIR EQUIVALENCE RATIO FOR INDOLENE FUEL,2000 RPM,16 IN.HG,MBT SPARK.

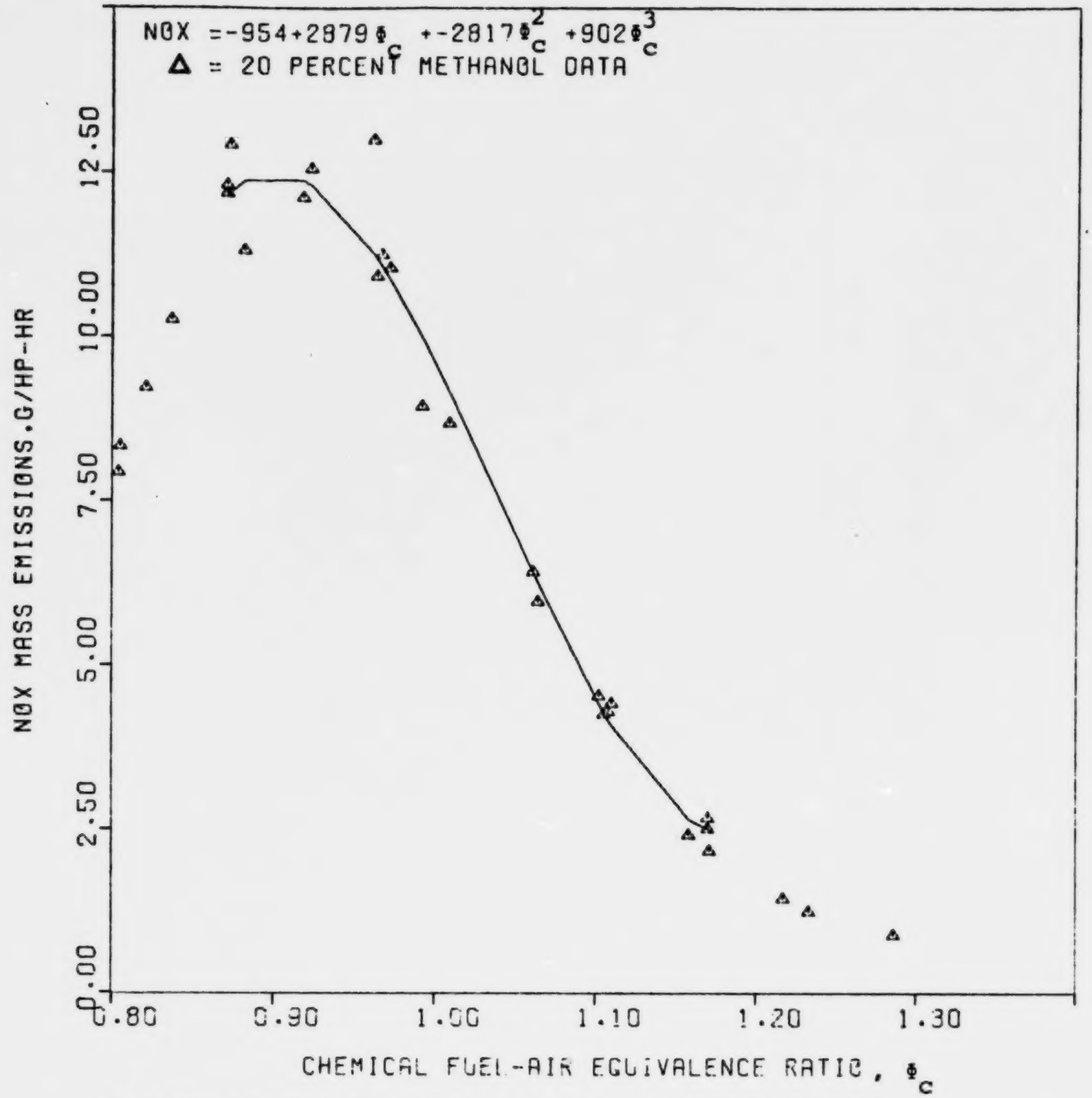


FIGURE 23 NOX MASS EMISSIONS VS. CHEMICAL FUEL-AIR EQUIVALENCE RATIO FOR 20 PERCENT METHANOL-INDOLENE BLEND FUEL,2000 RPM,16 IN.HG,MBT SPARK.

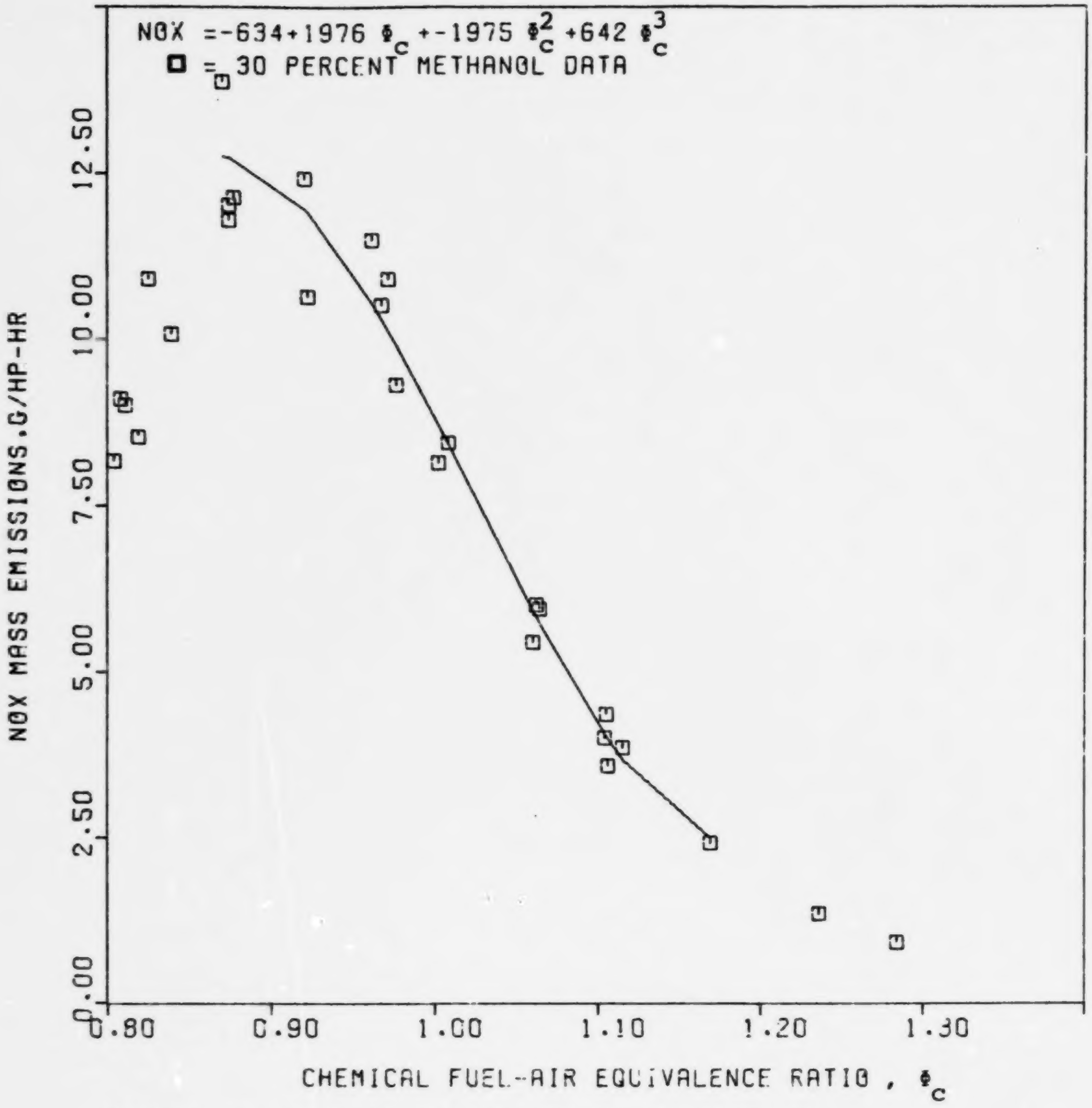


FIGURE 24 NOX MASS EMISSIONS VS. CHEMICAL FUEL-AIR EQUIVALENCE RATIO FOR 30 PERCENT METHANOL-INDOLENE BLEND FUEL.2000 RPM.16 IN. HG.MBT SPARK.

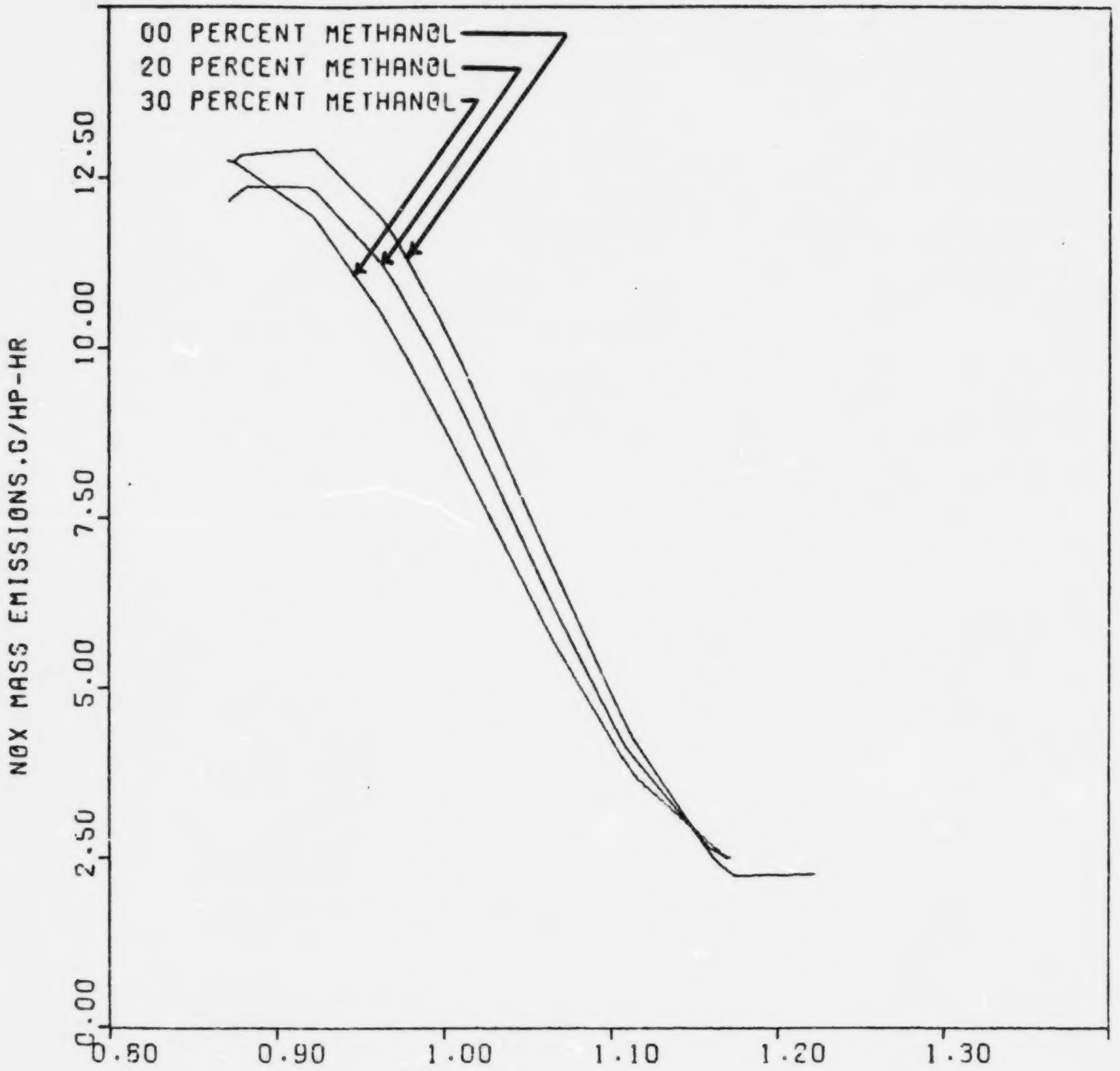


FIGURE 25 EQUATION (1) REGRESSION MODEL CURVES FOR NOX MASS EMISSIONS VS. CHEMICAL FUEL-AIR EQUIVALENCE RATIO.2000 RPM. 16 IN.HG.MBT SPARK.

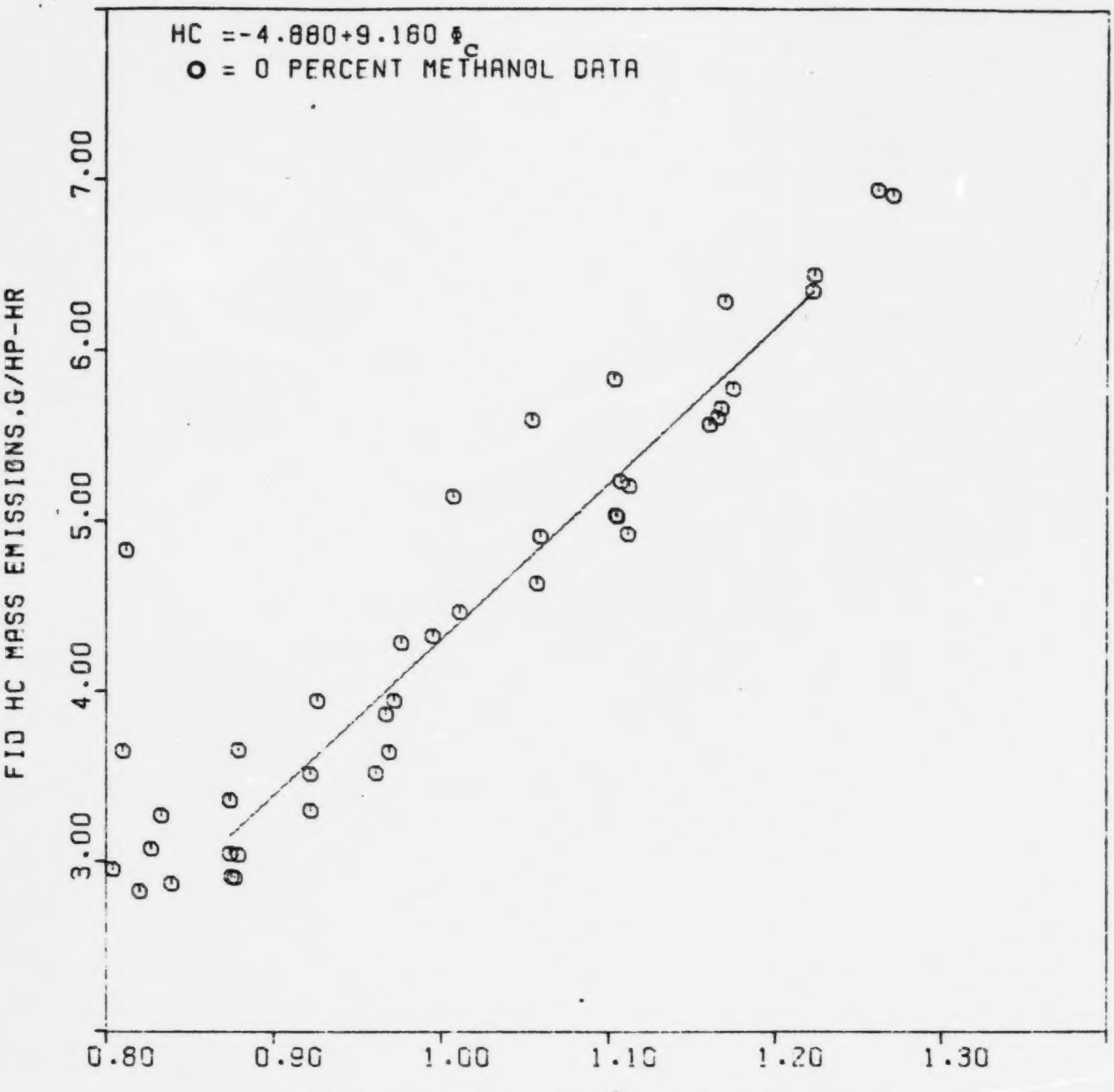


FIGURE 26 FID HC MASS EMISSIONS VS. CHEMICAL FUEL-AIR EQUIVALENCE RATIO FOR INDOLENE FUEL.2000 RPM.16 IN.HG.MBT SPARK.

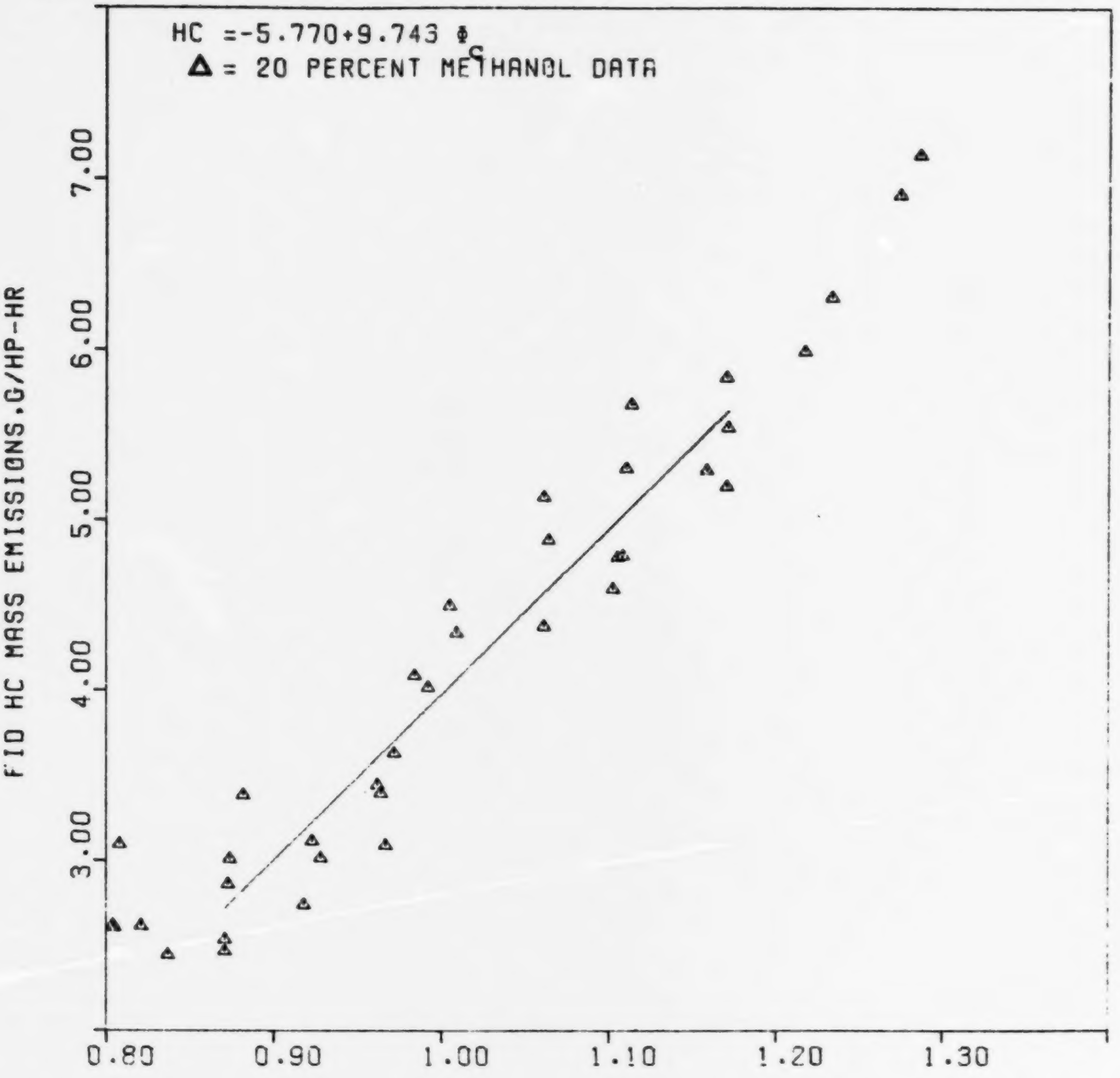


FIGURE 27 FID HC MASS EMISSIONS VS. CHEMICAL FUEL-AIR EQUIVALENCE RATIO FOR 20 PERCENT METHANOL-INDOLENE BLEND FUEL .2000 RPM.16 IN. HG.MBT SPARK.

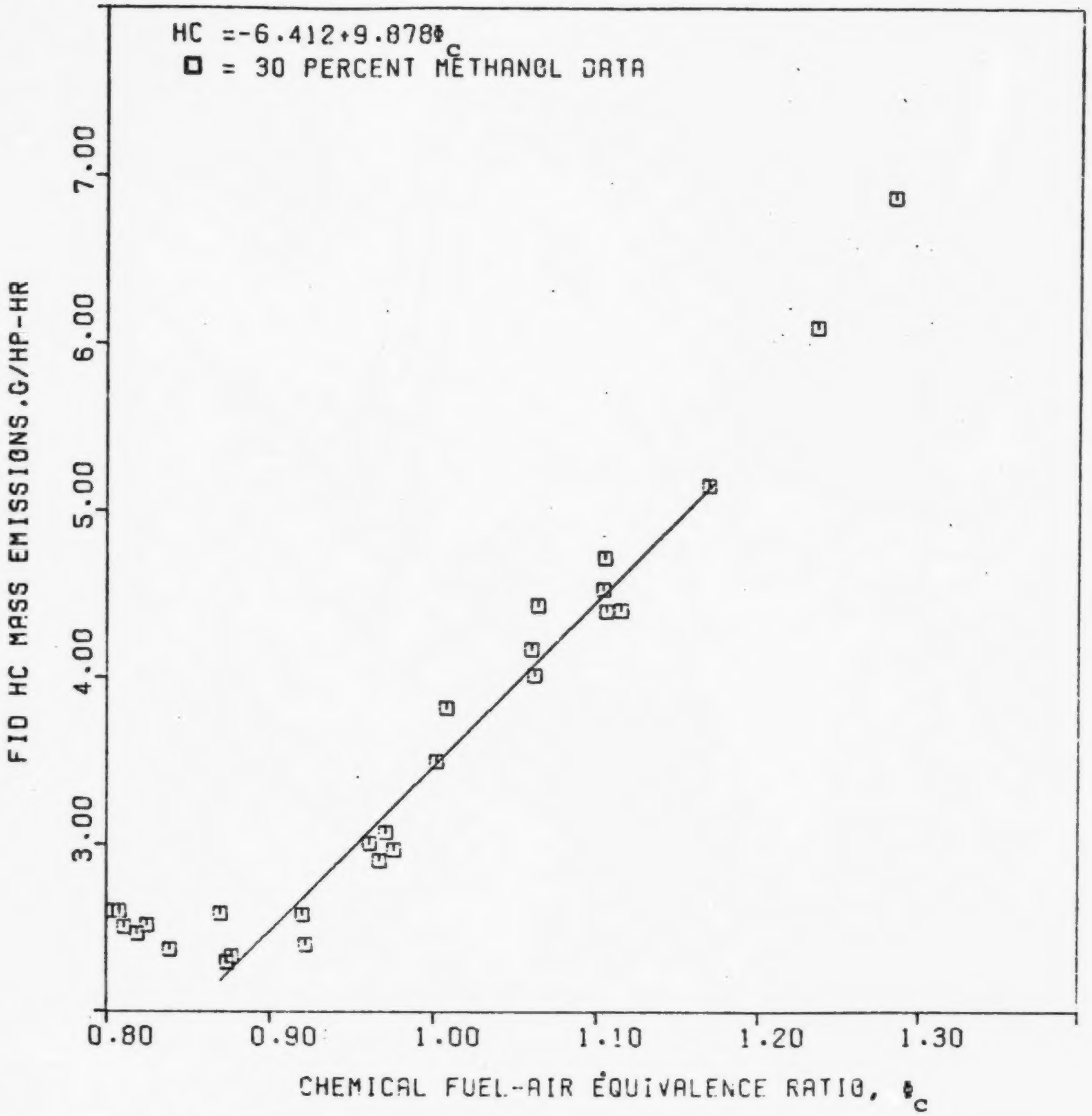


FIGURE 28 FID HC MASS EMISSIONS VS. CHEMICAL FUEL-AIR EQUIVALENCE RATIO FOR 30 PERCENT METHANOL-INDOLENE BLEND FUEL ,2000 RPM,16 IN. HG,MBT SPARK.

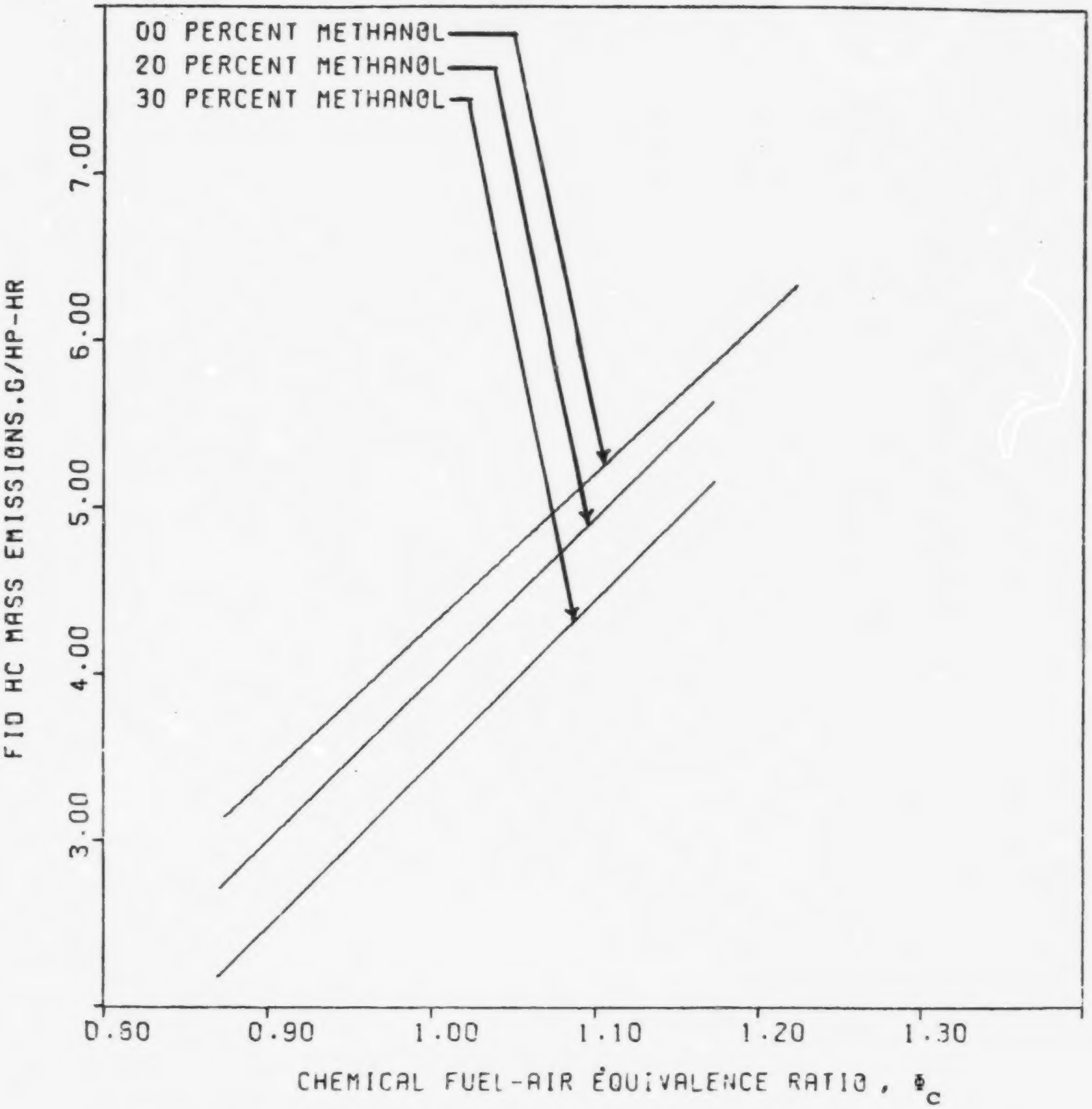


FIGURE **29** EQUATION (1) REGRESSION MODEL CURVES FOR FID HC MASS EMISSIONS VS. CHEMICAL FUEL-AIR EQUIVALENCE RATIO.2000 RPM.16 IN.HG.MBT SPARK.

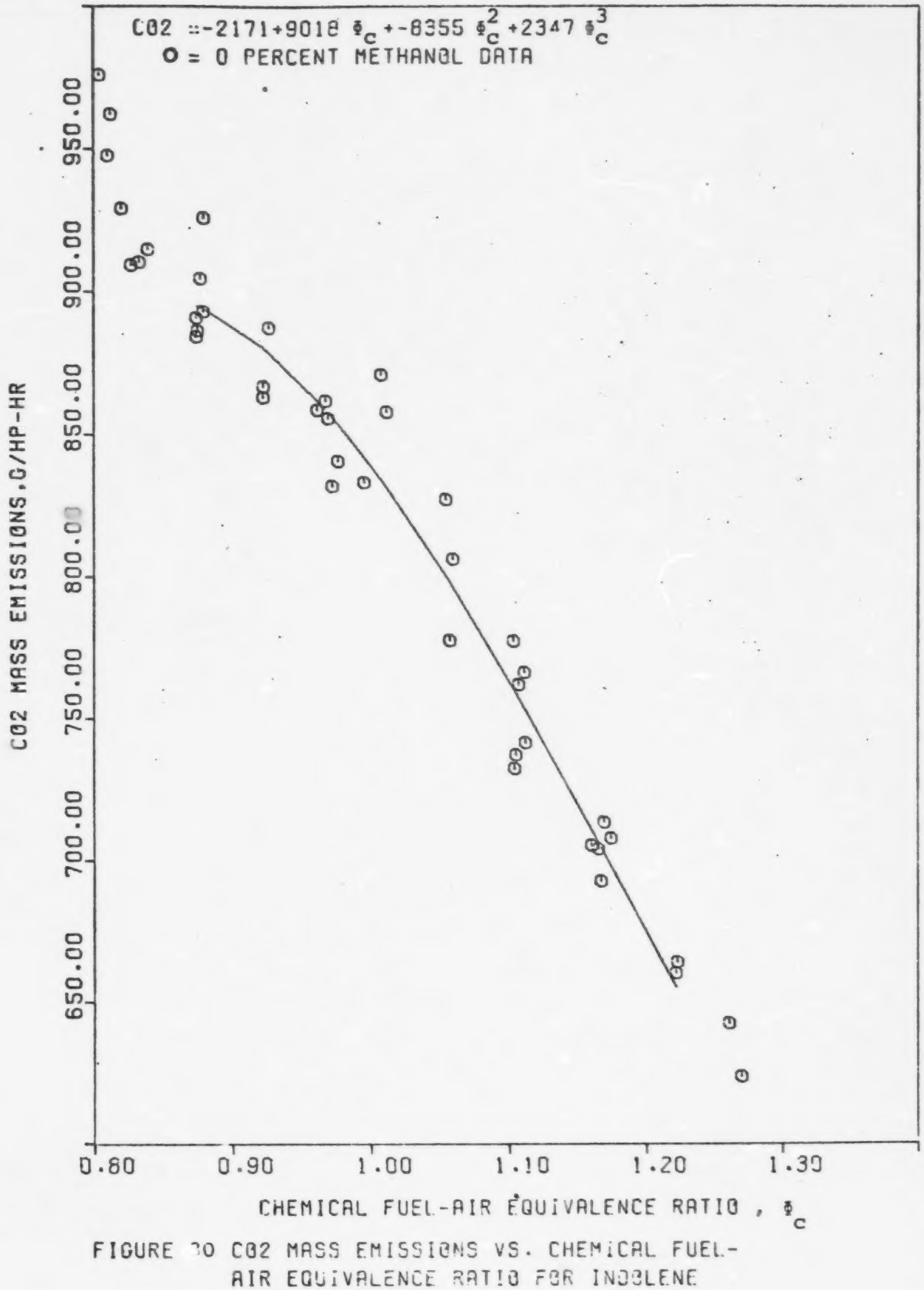


FIGURE 30 CO2 MASS EMISSIONS VS. CHEMICAL FUEL-AIR EQUIVALENCE RATIO FOR INDOLENE FUEL, 2000 RPM, 16 IN. HG, MBT SPARK.

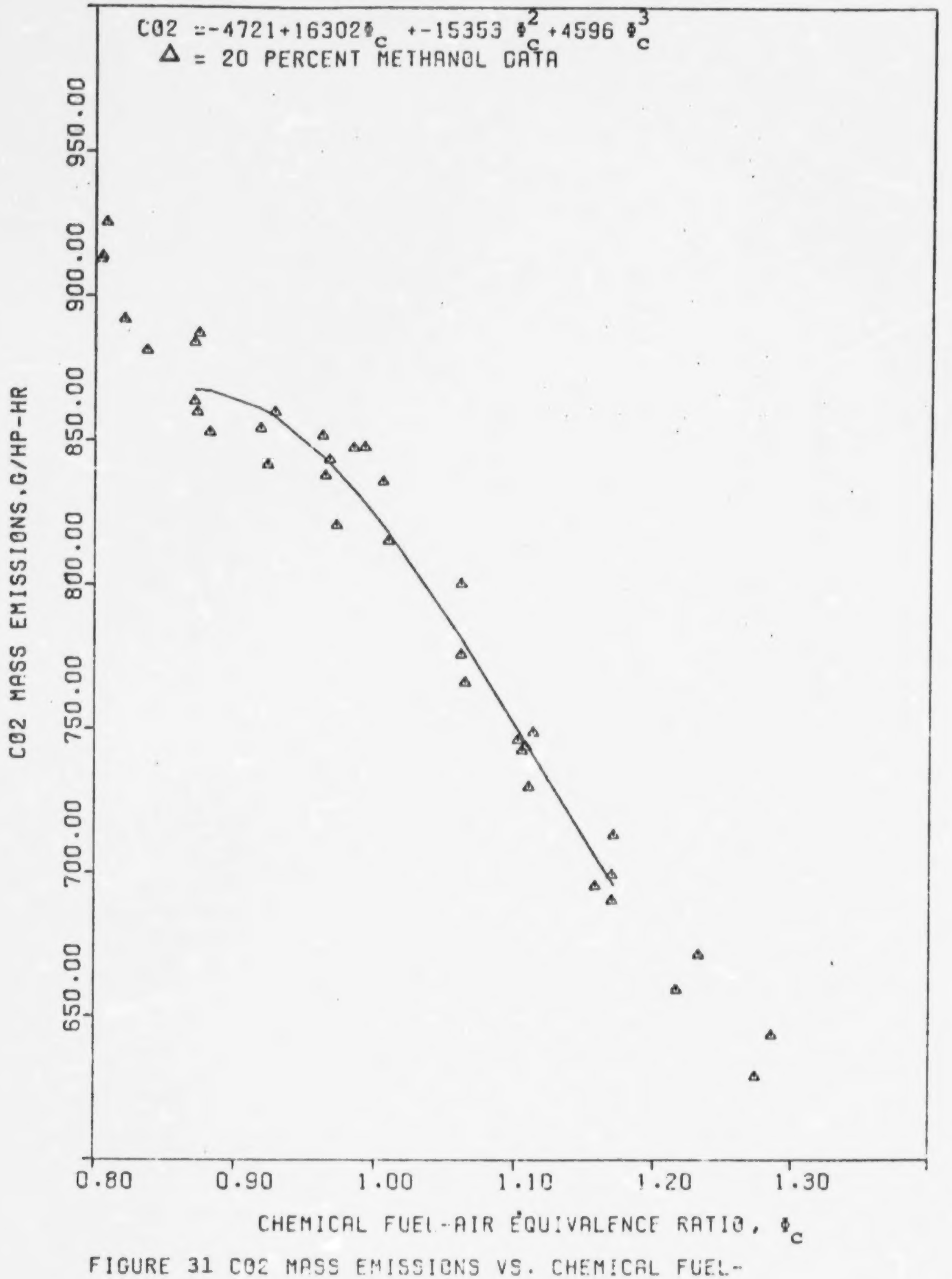


FIGURE 31 CO2 MASS EMISSIONS VS. CHEMICAL FUEL-AIR EQUIVALENCE RATIO FOR 20 PERCENT METHANOL-INDOLENE BLEND FUEL.2000 RPM.16 IN.HG.MBT SPARK.

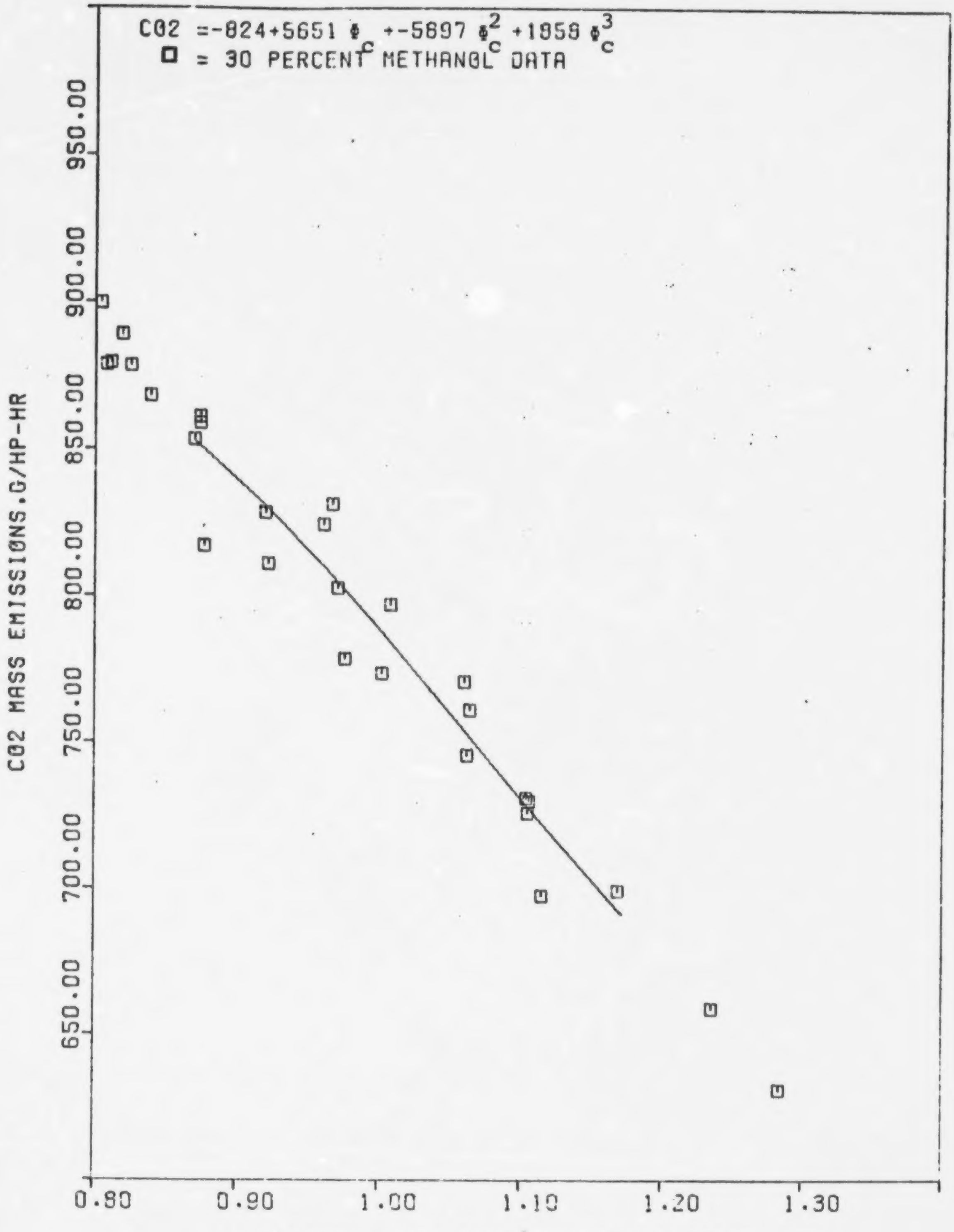


FIGURE 32 CO2 MASS EMISSIONS VS. CHEMICAL FUEL-AIR EQUIVALENCE RATIO FOR 20 PERCENT METHANOL-INDOLENE BLEND FUEL.2000 RPM.16 IN.HG.MBT SPARK.

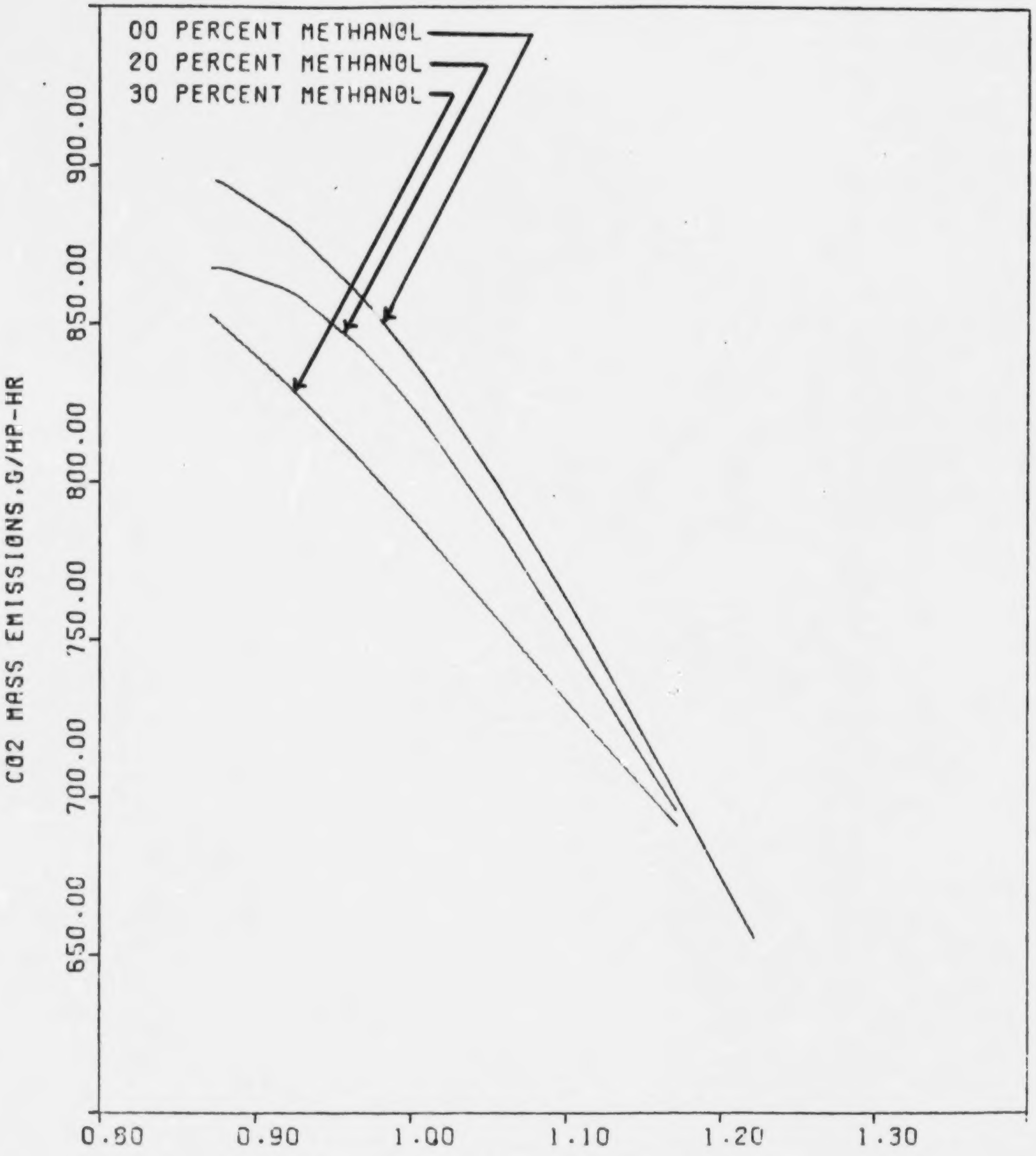


FIGURE 33 EQUATION (1) REGRESSION MODEL CURVES FOR CO2 MASS EMISSIONS VS. CHEMICAL FUEL-AIR EQUIVALENCE RATIO,2000 RPM, 16 IN.HG,MBT SPARK.

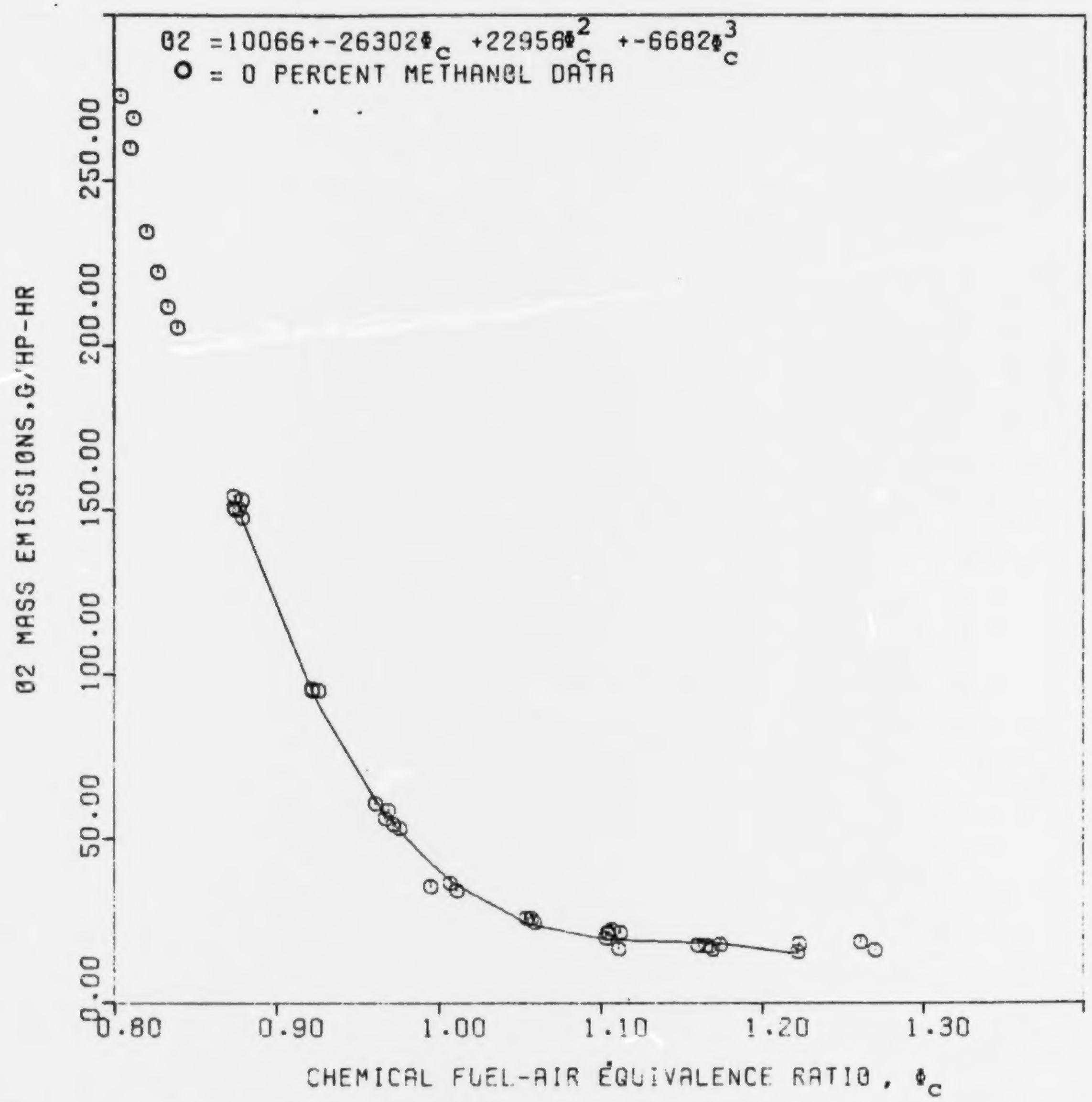


FIGURE 34 OXYGEN MASS EMISSIONS VS. CHEMICAL FUEL-AIR EQUIVALENCE RATIO FOR INDOLENE FUEL.2000 RPM.16 IN HG.MBT SPARK.

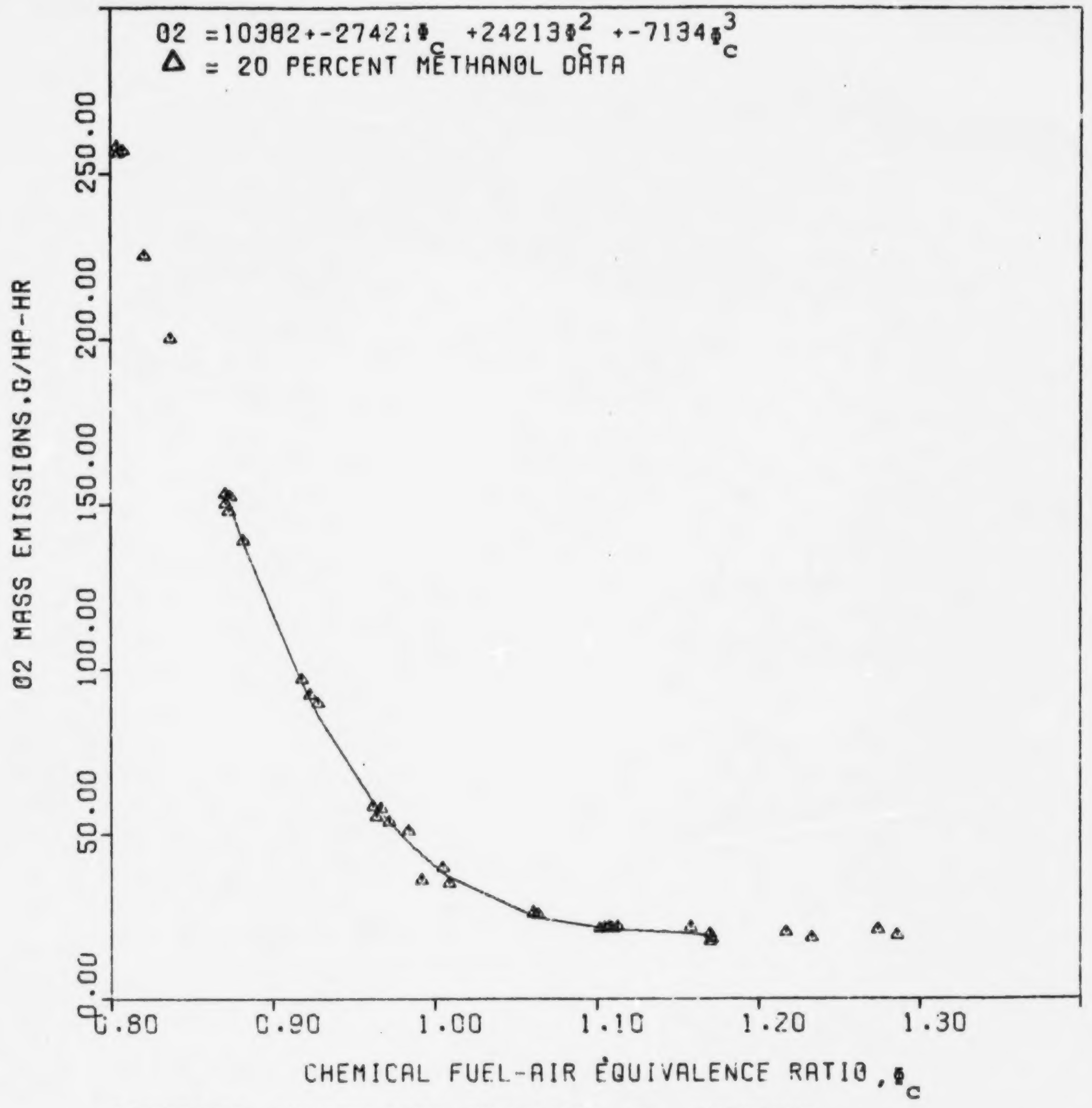


FIGURE 35 OXYGEN MASS EMISSIONS VS. CHEMICAL FUEL-AIR EQUIVALENCE RATIO FOR 20 PERCENT METHANOL-INDOLENE BLEND FUEL .2000 RPM.16 IN.HG.MBT SPARK.

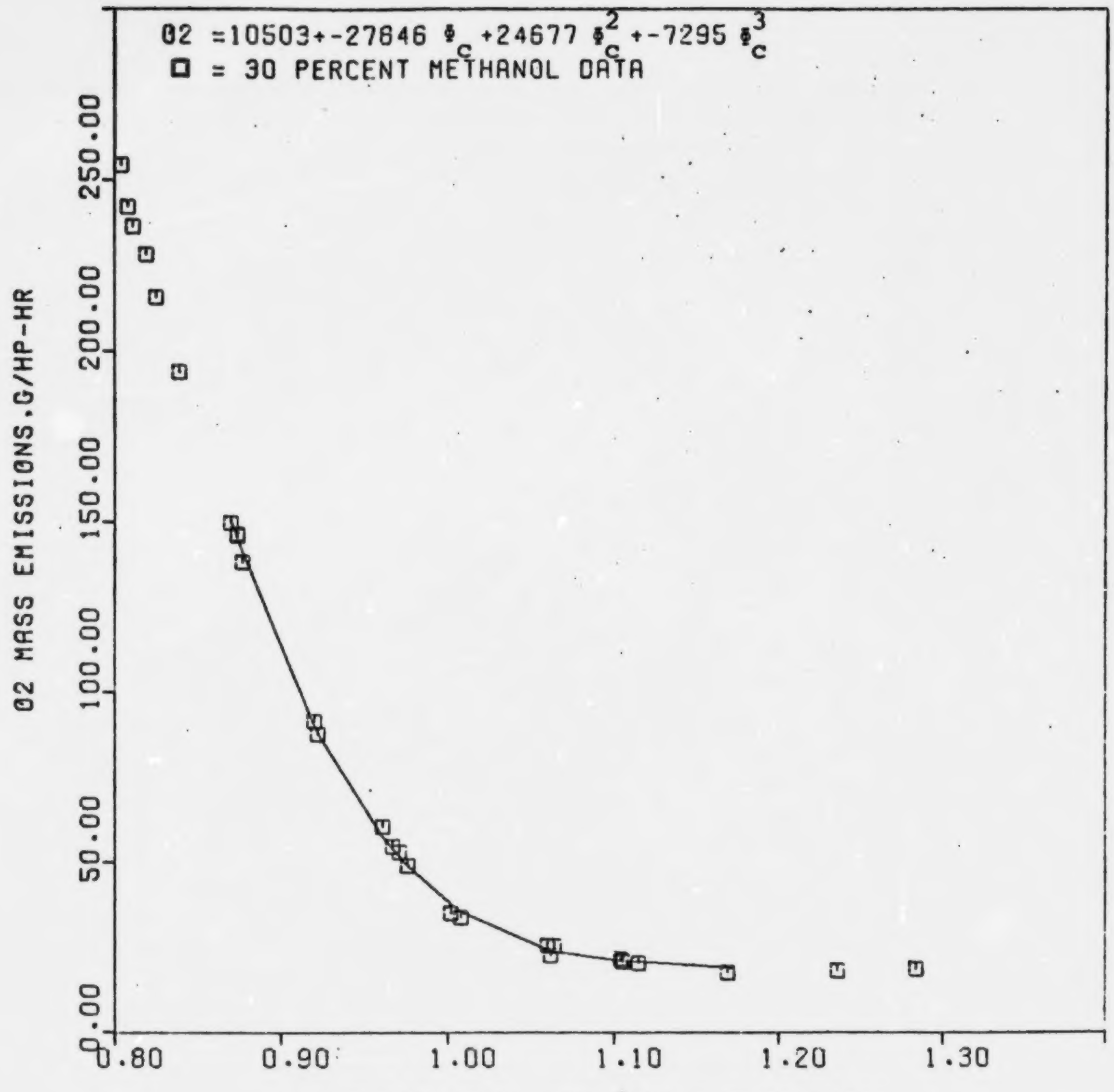


FIGURE 36 OXYGEN MASS EMISSIONS VS. CHEMICAL FUEL-AIR EQUIVALENCE RATIO FOR 30 PERCENT METHANOL-INDOLENE BLEND FUEL .2000 RPM.16 IN.HG.MBT SPARK.

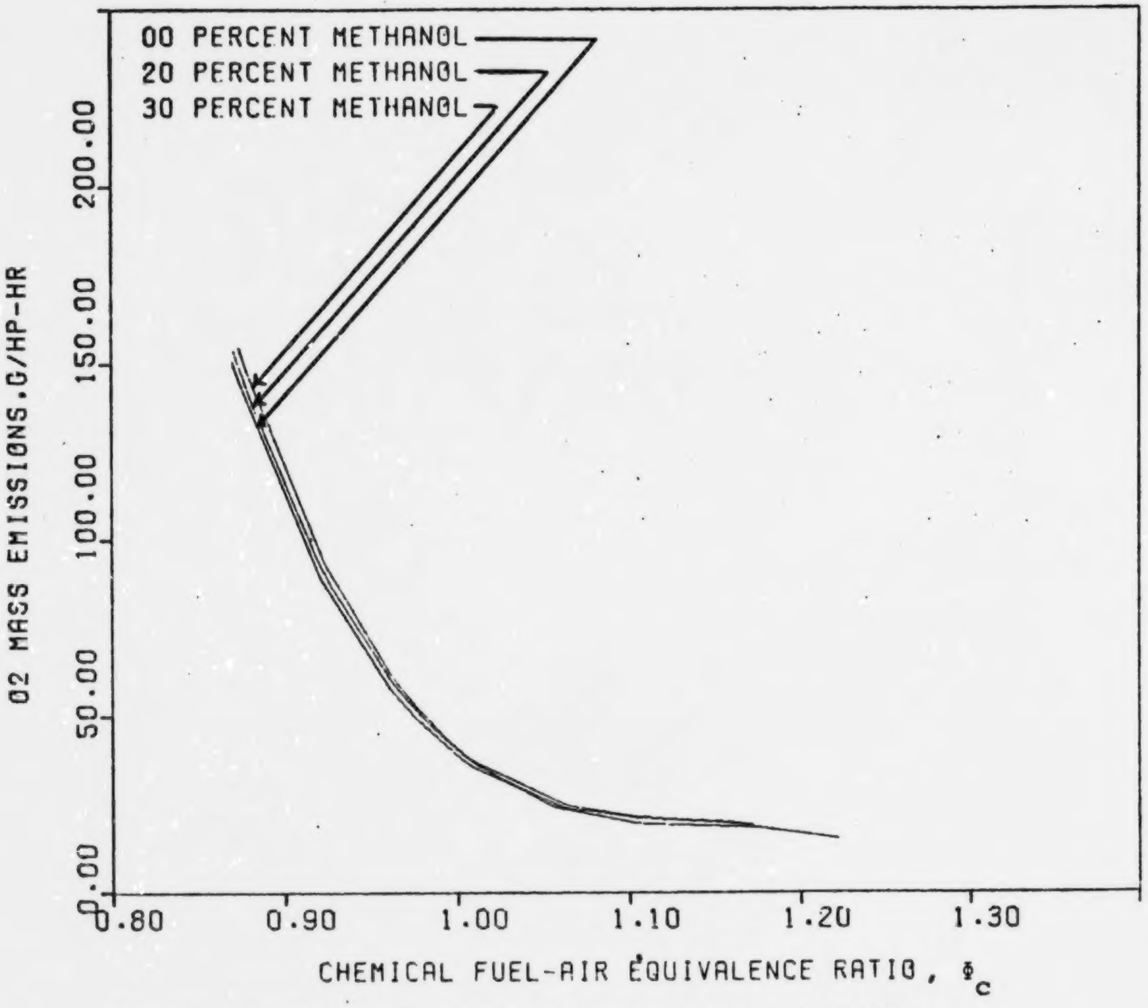


FIGURE 37 EQUATION (1) REGRESSION MODEL CURVES FOR O2 MASS EMISSIONS VS. CHEMICAL FUEL-AIR EQUIVALENCE RATIO.2000 RPM. 16 IN.HG.MBT SPARK.

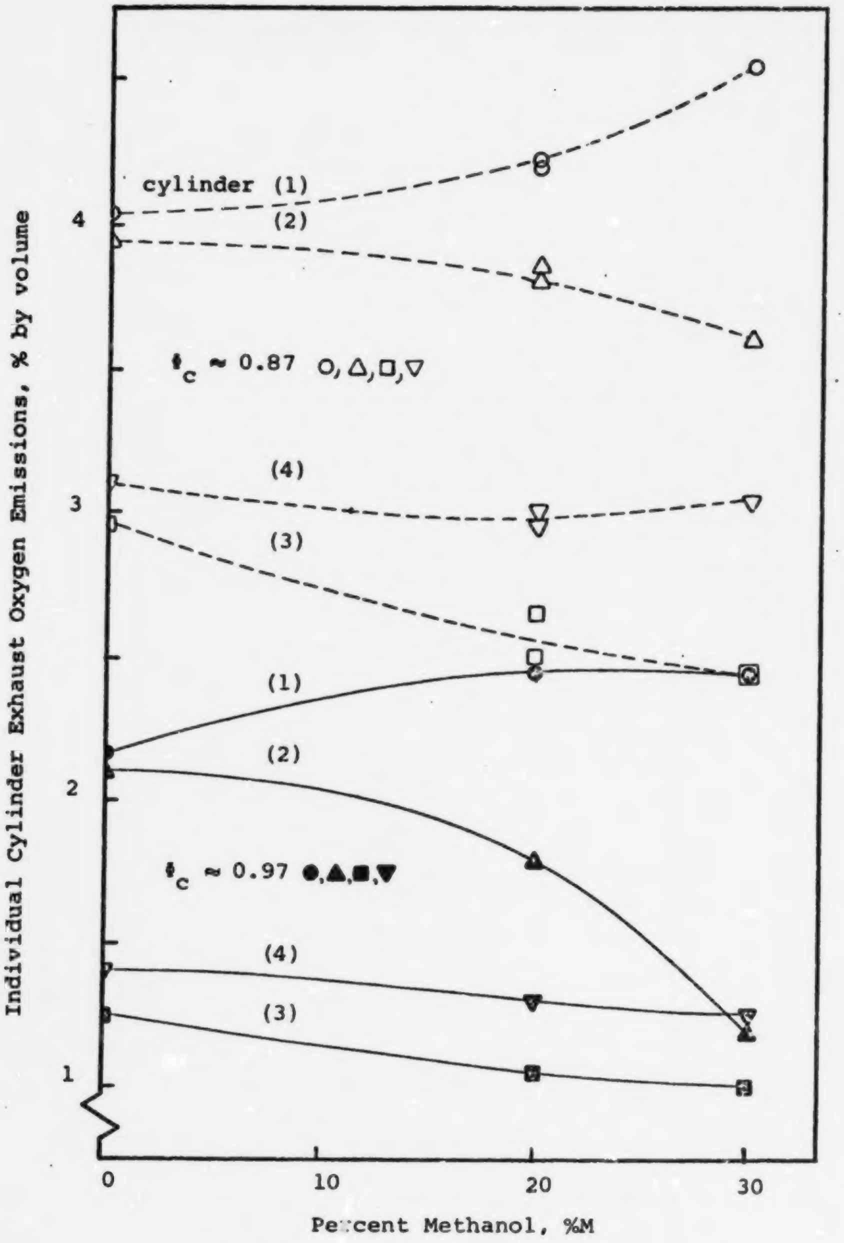


Figure 38 - Individual cylinder Exhaust Oxygen Emissions versus Percent Methanol, 2000 RPM, 16 in.Hg (54 kPa), MBT spark.

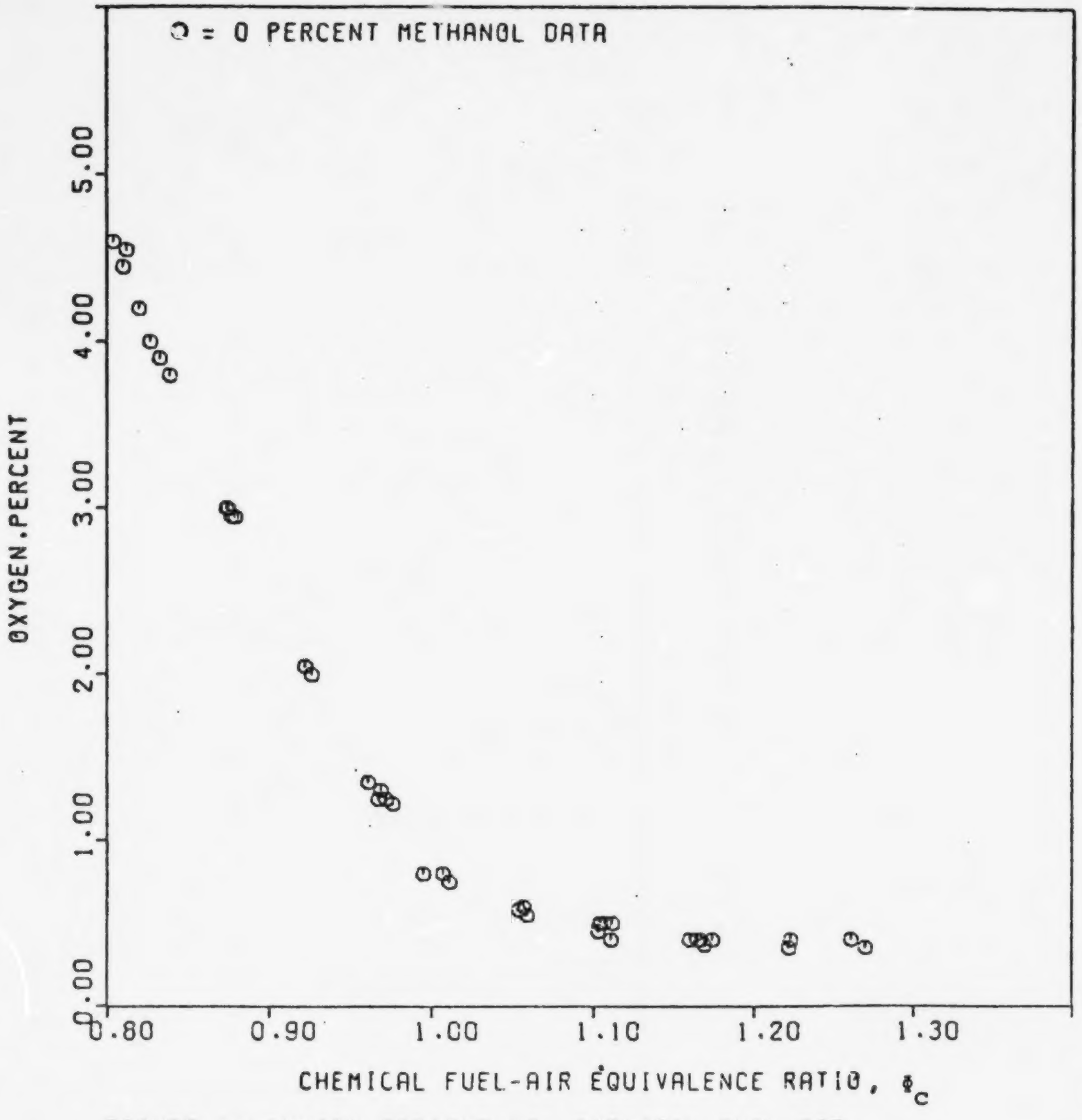


FIGURE 39 OXYGEN PERCENT VS. CHEMICAL FUEL-AIR EQUIVALENCE RATIO FOR INDOLENE FUEL. 2000 RPM.16 IN. HG.MBT SPARK.

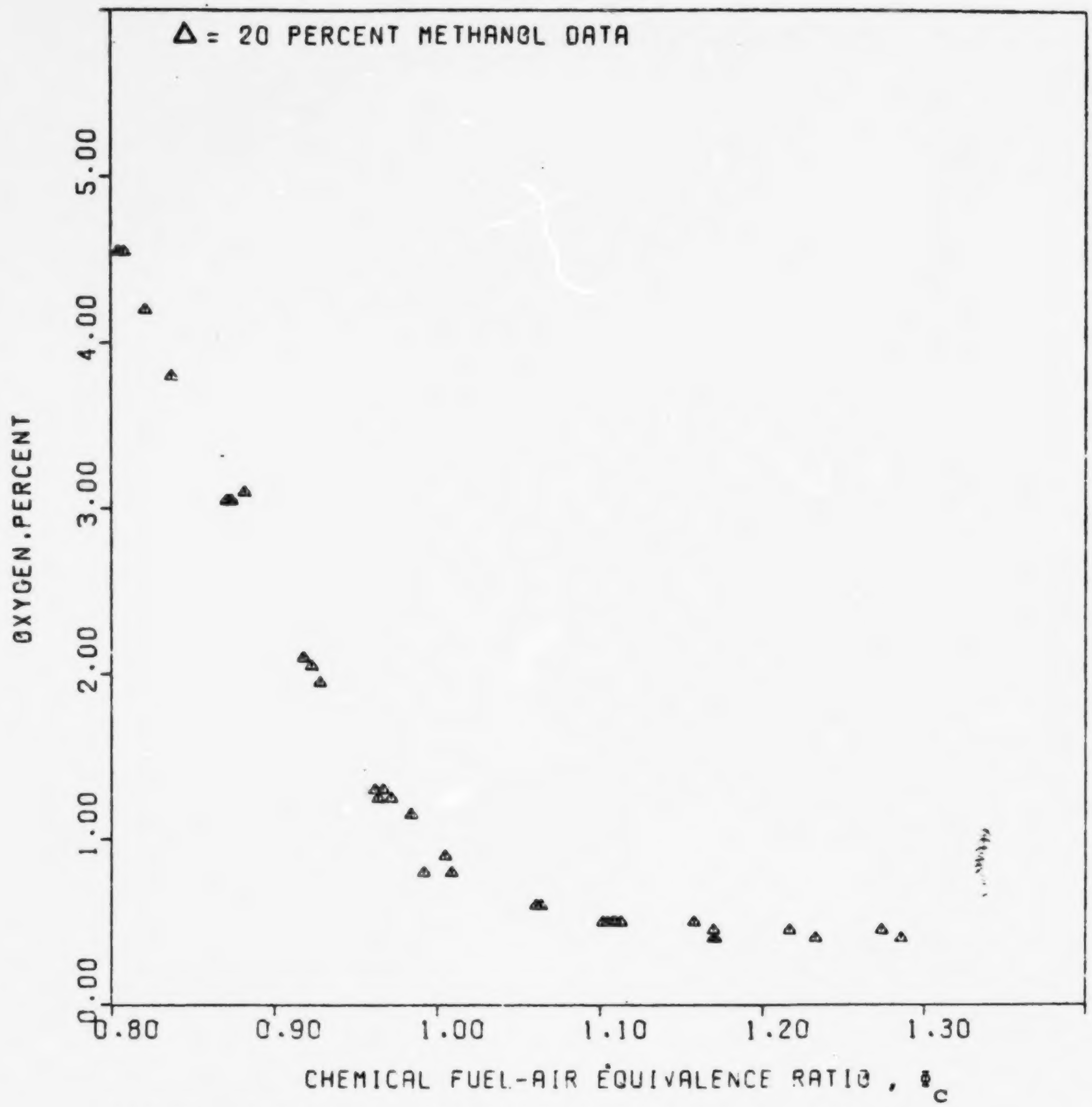


FIGURE 40 OXYGEN PERCENT VS. CHEMICAL FUEL-AIR EQUIVALENCE RATIO FOR 20 PERCENT METHANOL-INDOLENE BLEND FUEL, 2000 RPM, 16 IN. HG, MBT SPARK.

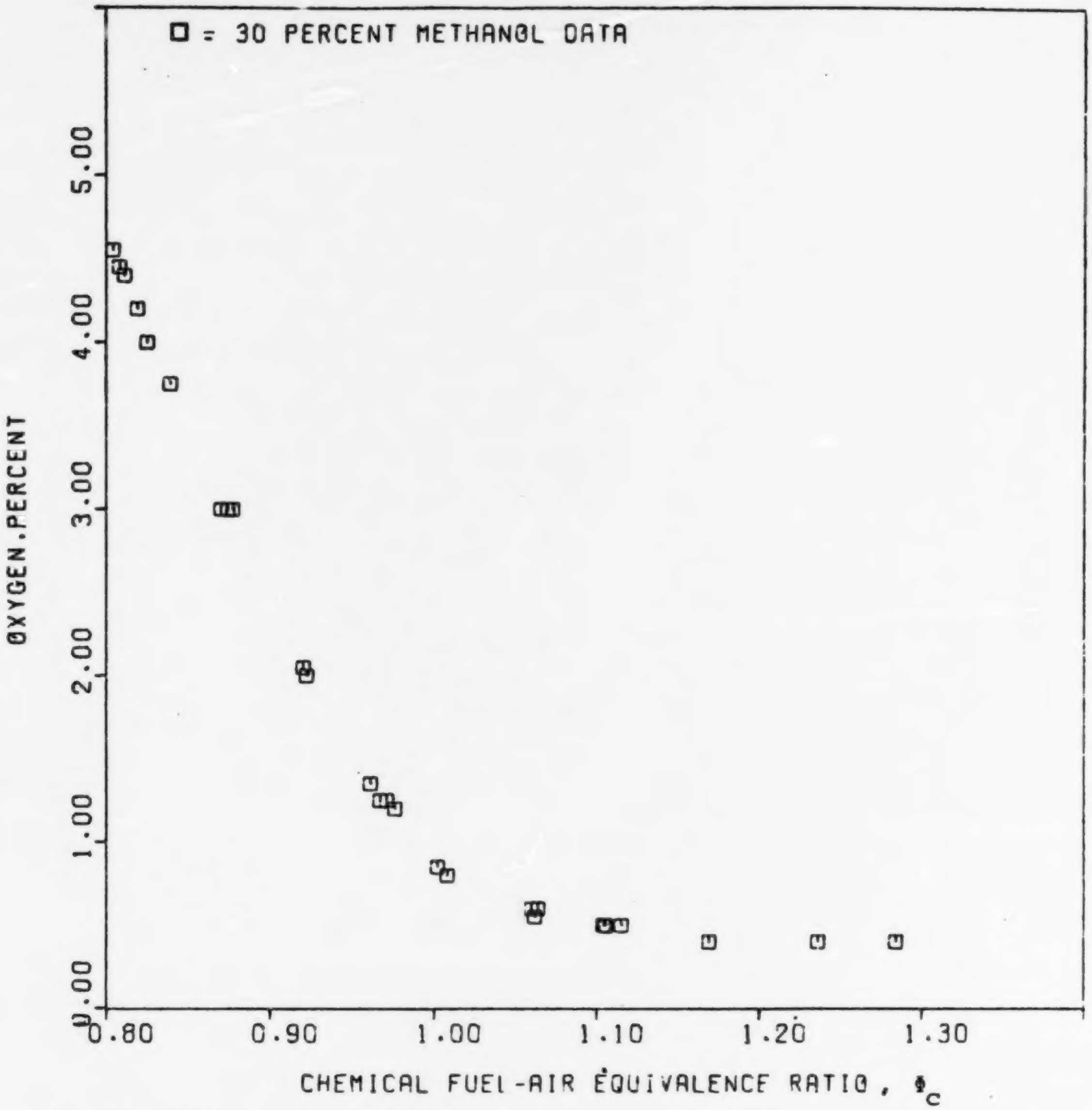


FIGURE 41 OXYGEN PERCENT VS CHEMICAL FUEL-AIR EQUIVALENCE RATIO FOR 30 PERCENT METHANOL-INDOLENE BLEND FUEL.2000 RPM.16 IN.HG.MBT SPARK.

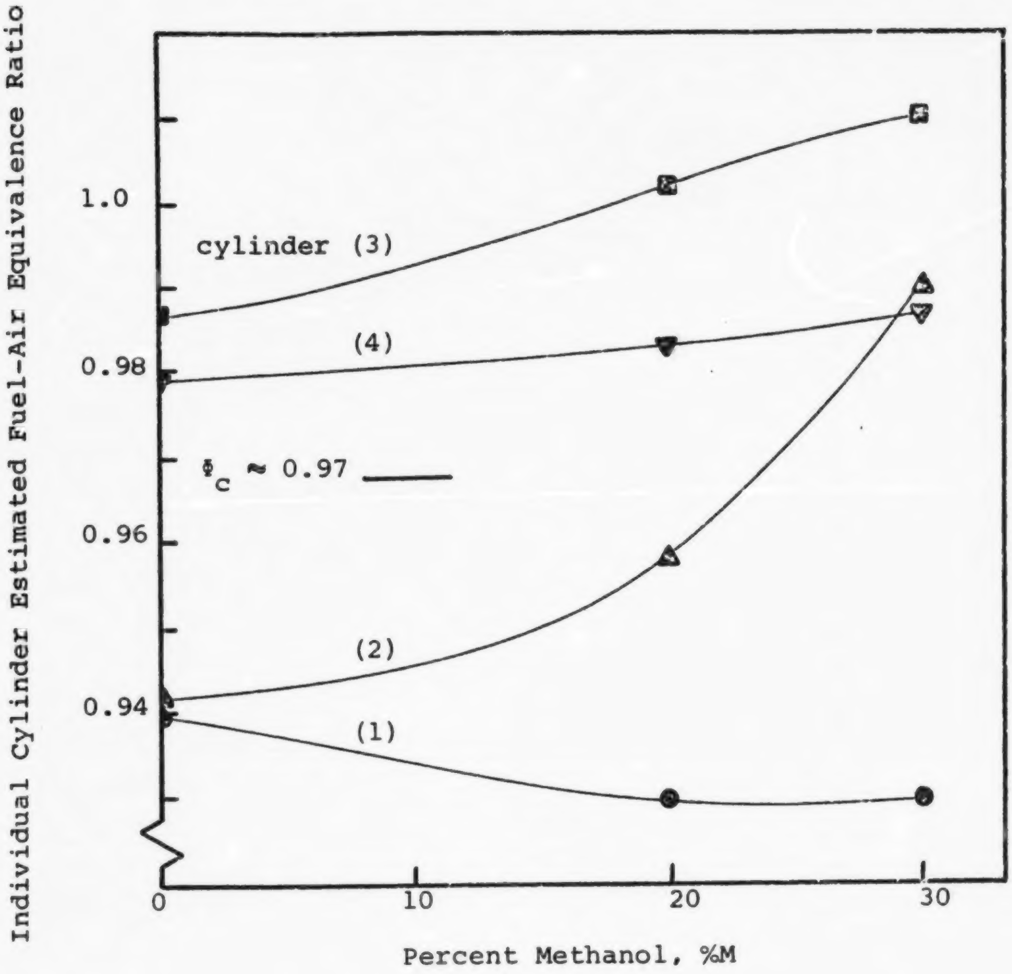


Figure 42 - Illustrates the Effect of Methanol on Geometric Distribution, 2000 RPM, 16 in. Hg (54 kPa), MBT spark, $\Phi_c \approx 0.97$

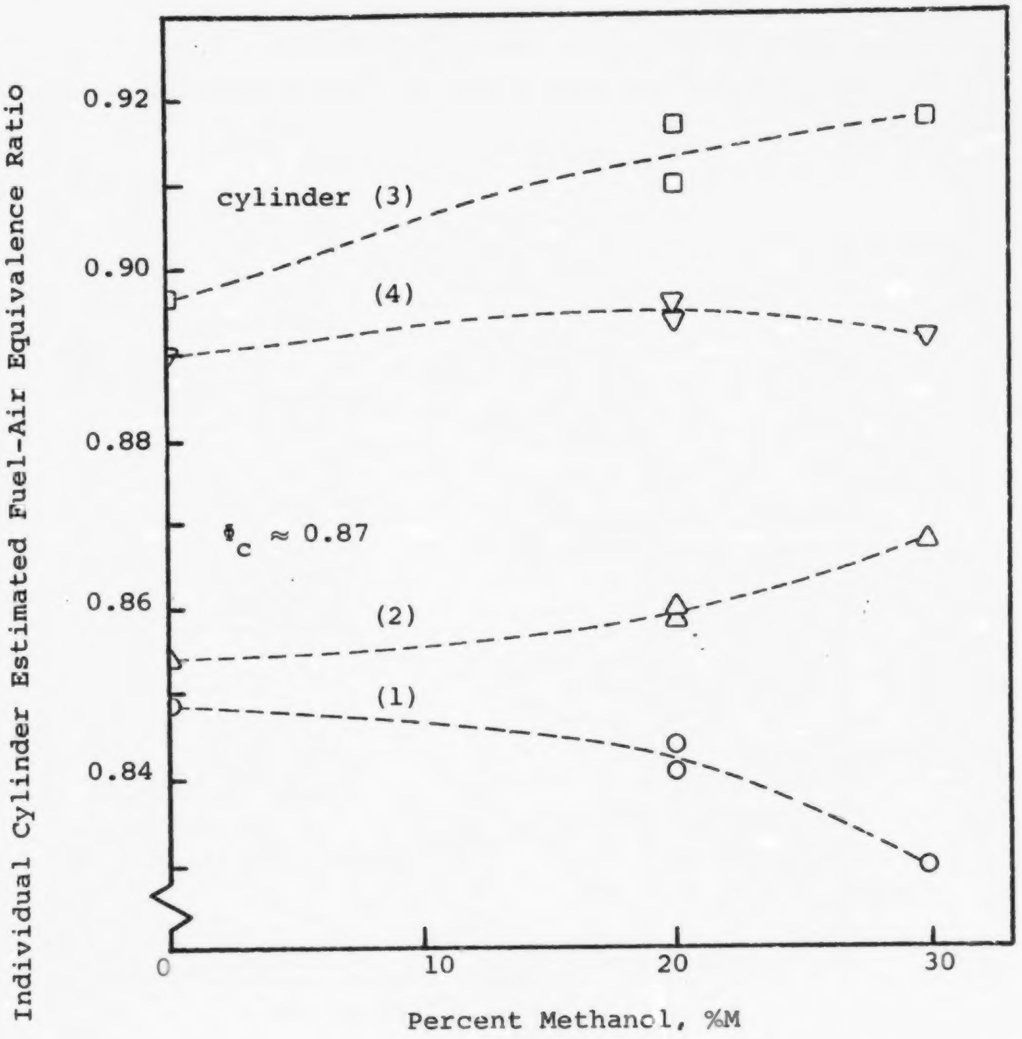


Figure 43 - Illustrates the Effect of Methanol on Geometric Distribution, 2000 RPM, 16 in. Hg (54 kPa), MBT spark, $\Phi_c \approx 0.87$

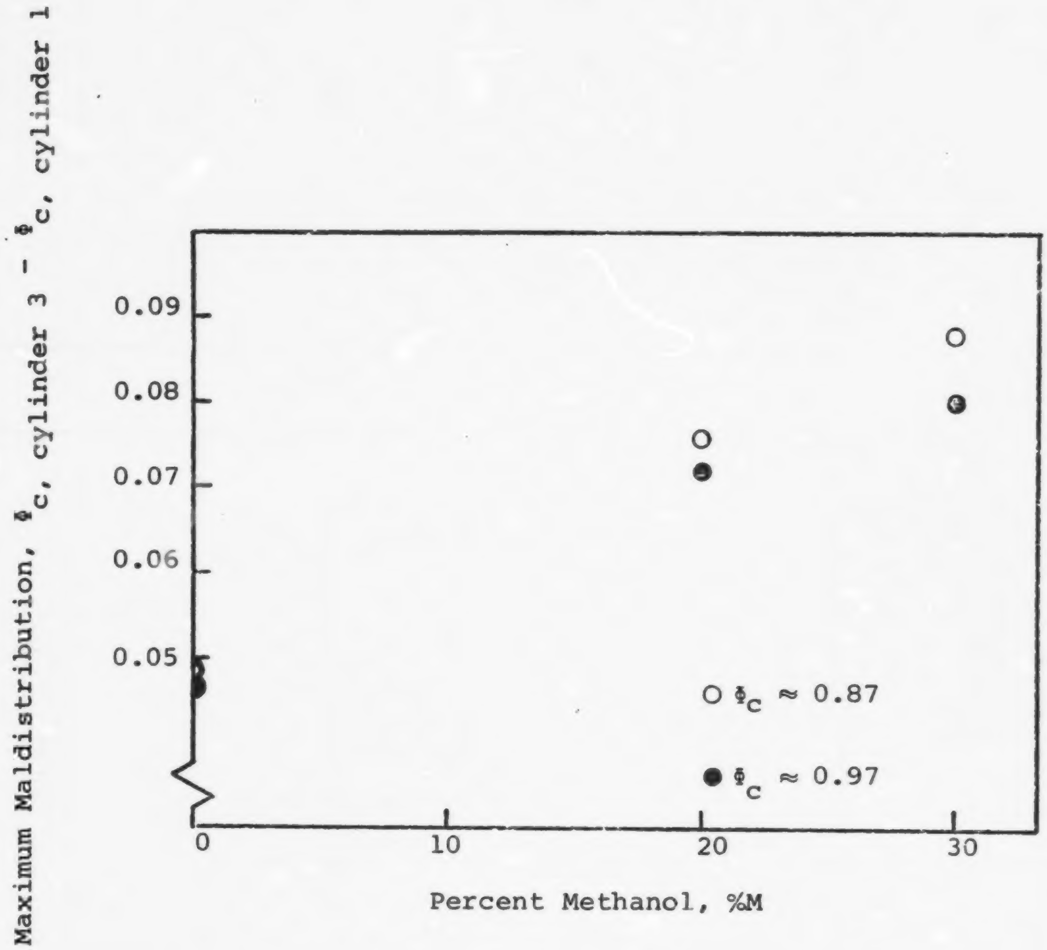


Figure 44 - Illustrates the Effect of Methanol on Maximum Spread in Geometric Fuel-Air Equivalence Ratios as Determined from Figures 61 and 62

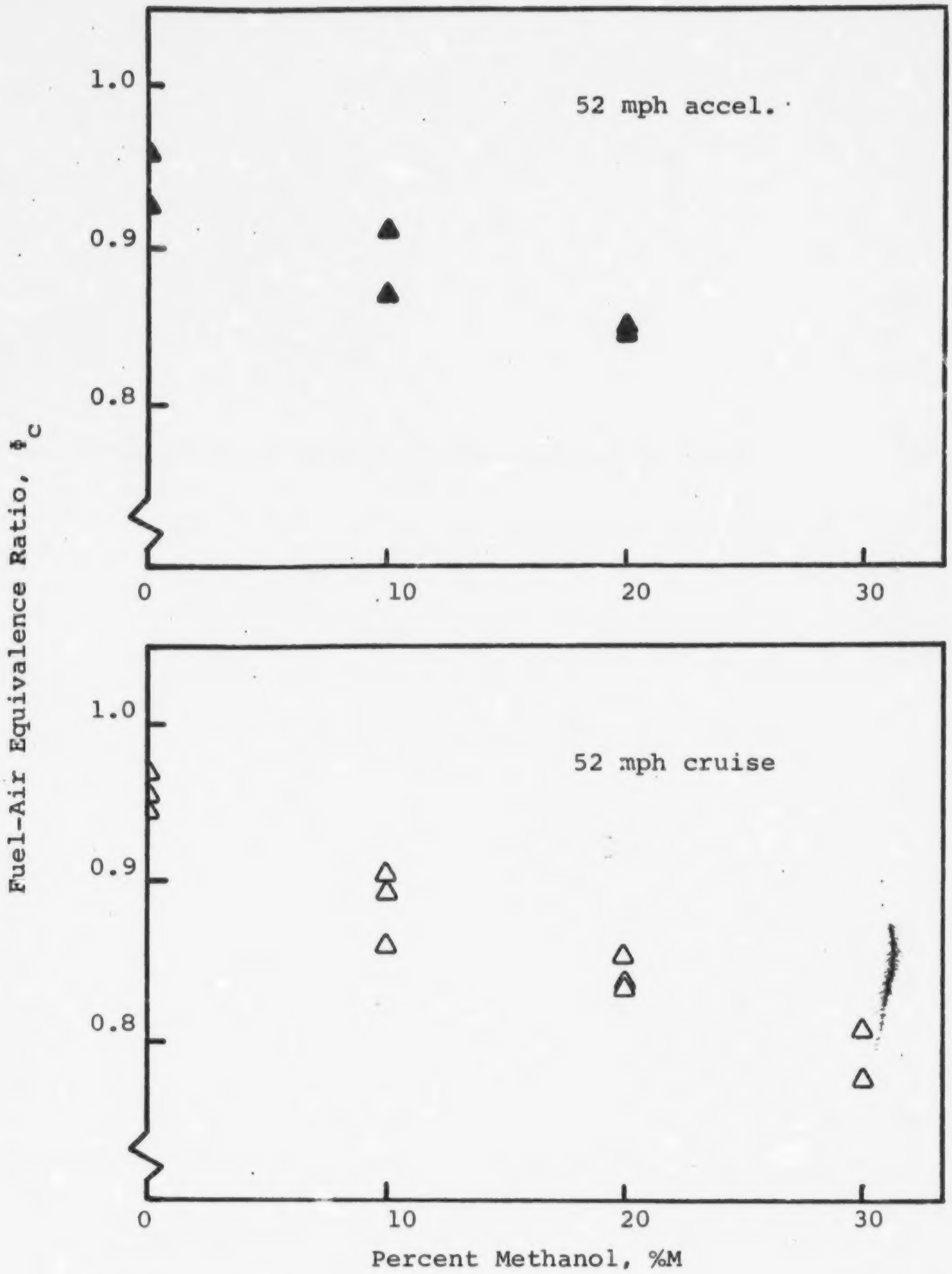


Figure 45 - Illustrates the Reduction in Fuel-Air Equivalence Ratio when Methanol Blends are Substituted for Indolene with No Engine Adjustments (Type I Tests)

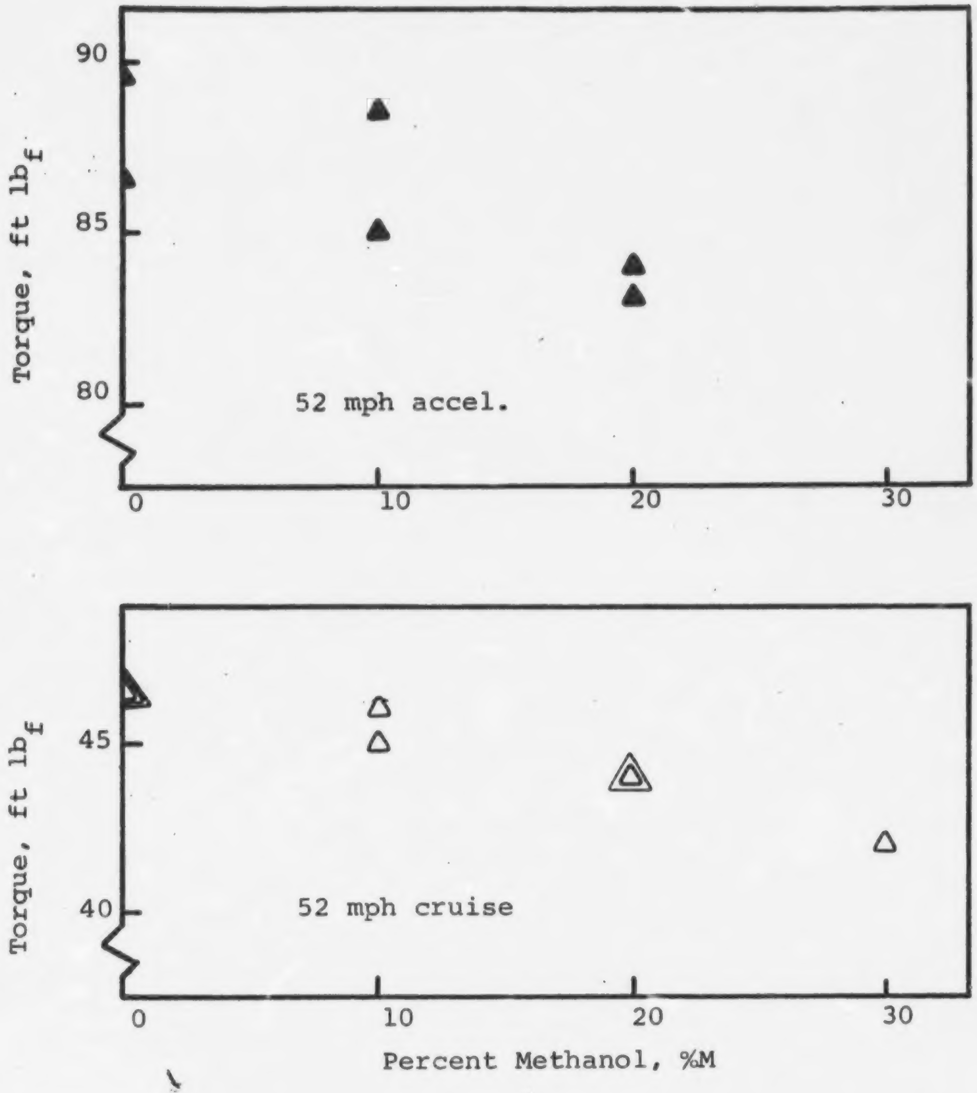


Figure 46a- Illustrates the Reduction in Torque Occurring when Methanol Blends are substituted for Indolene with No Engine Adjustments (Type I Tests)

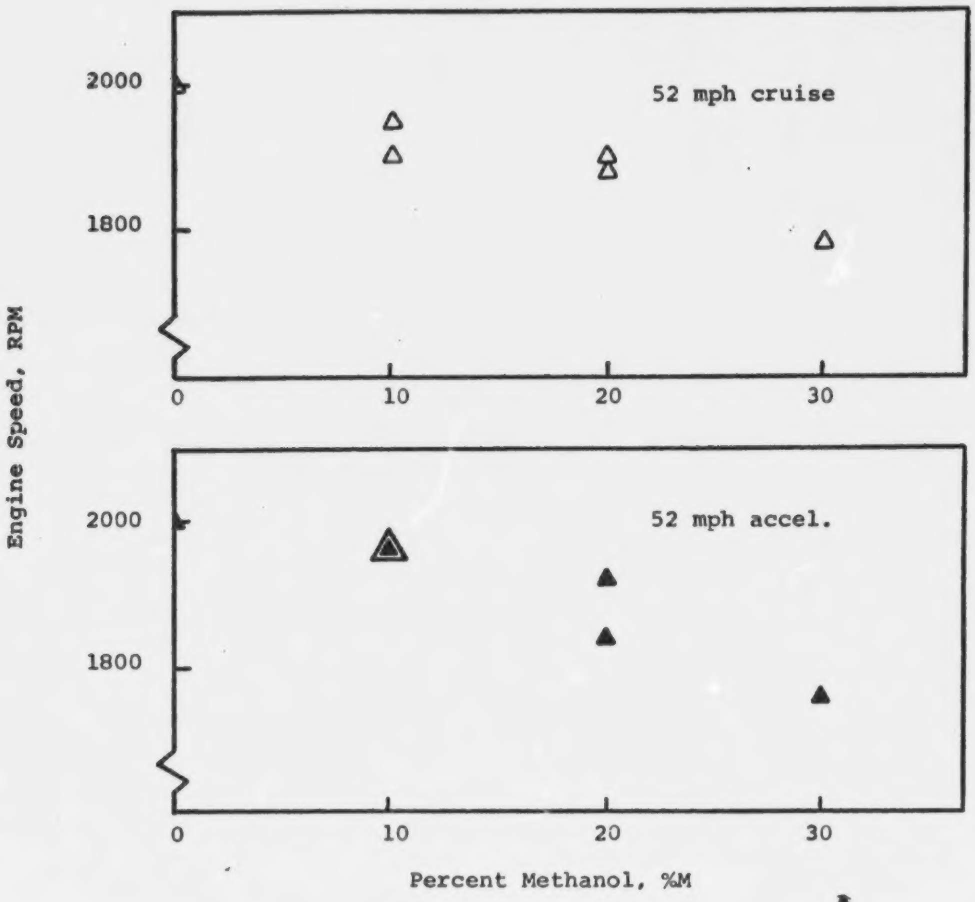


Figure 46b - Illustrates the Reduction in Engine Speed Occurring when Methanol Blends are Substituted for Indolene with No Engine Adjustments (Type I Tests)

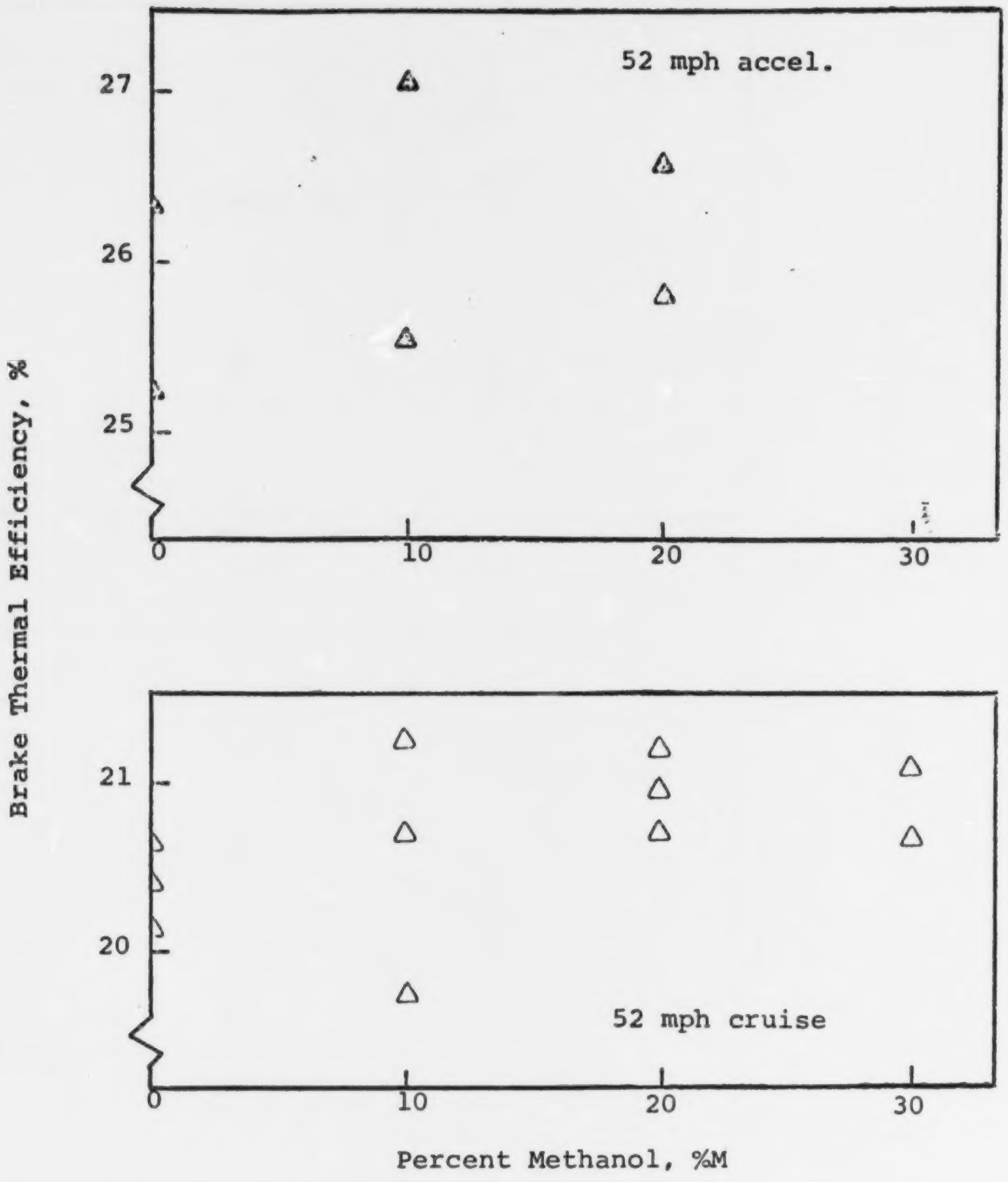


Figure 47 - Brake Thermal Efficiency When Methanol Blends are Substituted for Indolene with No Engine Adjustments (Type I tests).

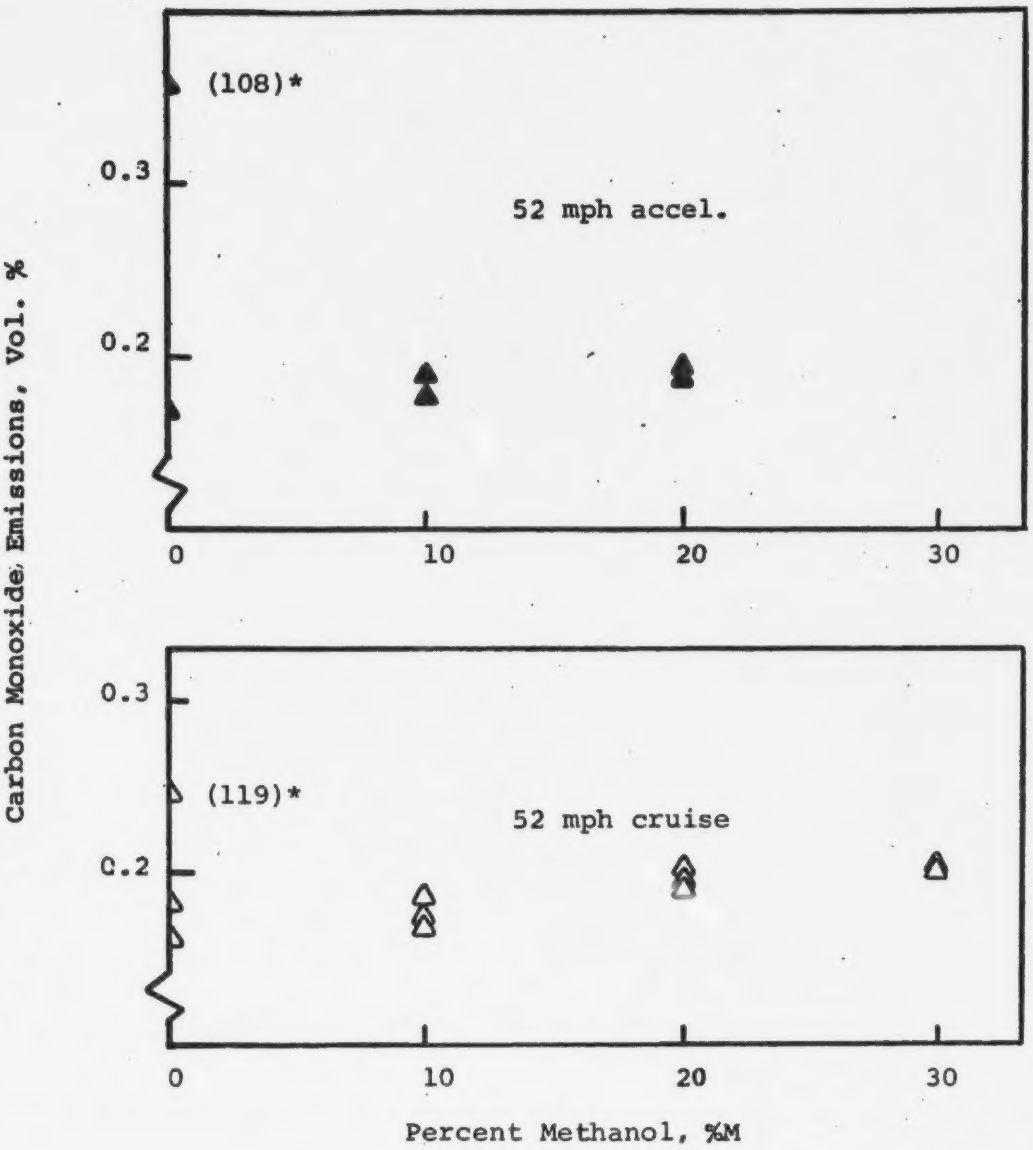


Figure 48a - Carbon Monoxide Volume Emissions when Methanol Blends are substituted for Indolene with No Engine Adjustments (Type I Tests)

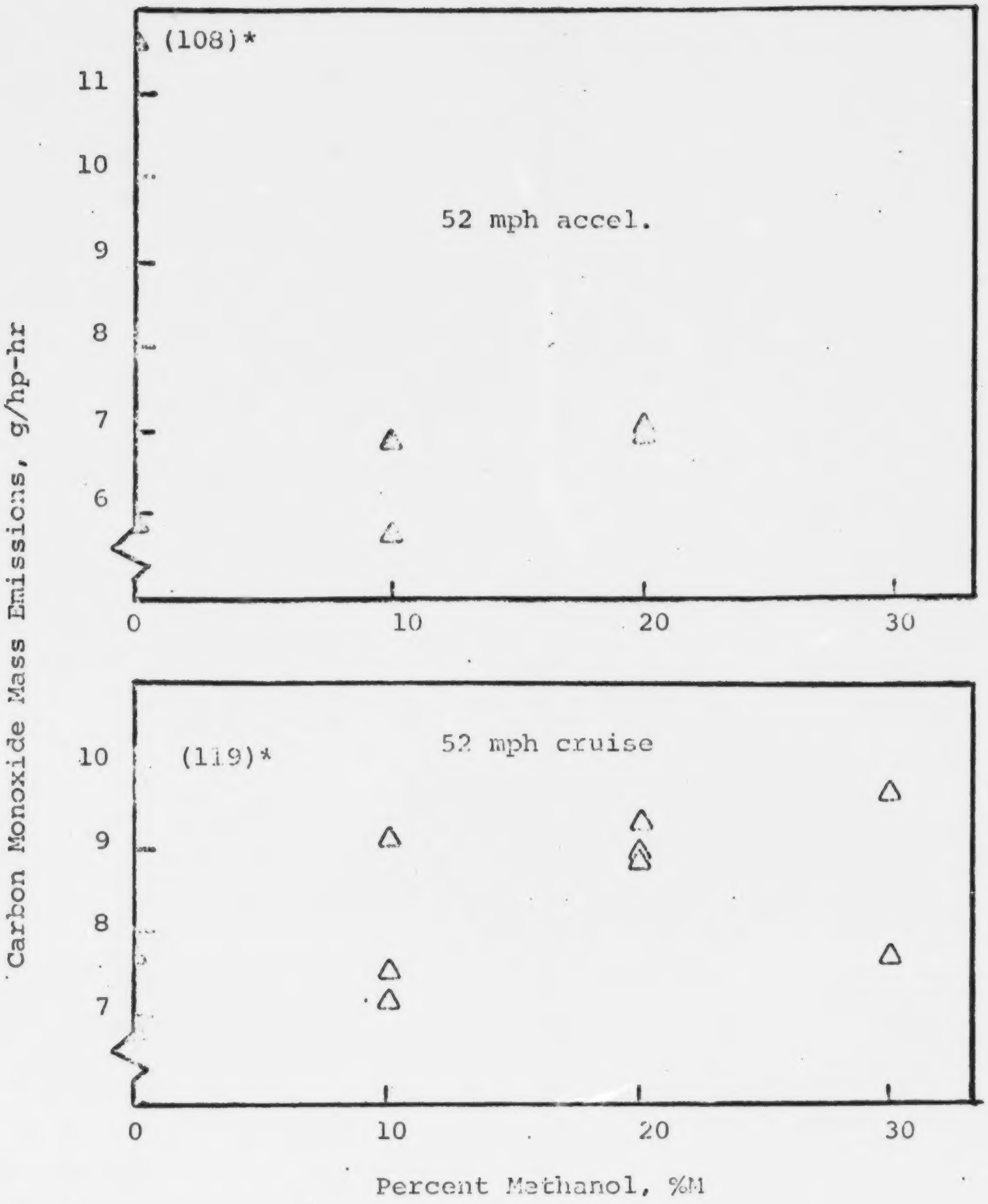


Figure 48b - Carbon Monoxide Mass Emissions When Methanol Blends are Substituted for Indolene with No Engine Adjustments (Type I Tests).

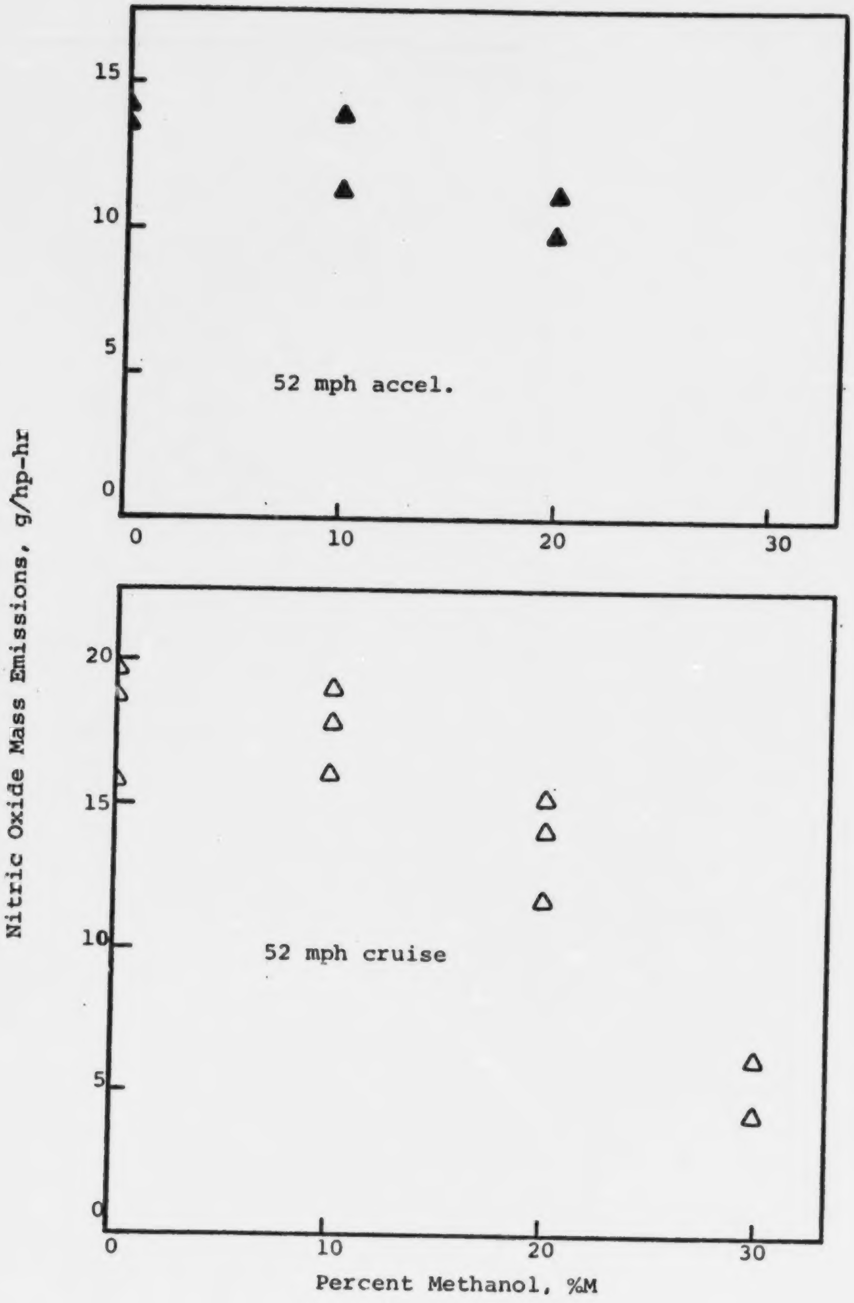


Figure 49a- Illustrates the Reduction in Nitric Oxide Mass Emissions Occurring When Methanol Blends are Substituted for Indolene with No Engine Adjustments (Type I Tests)

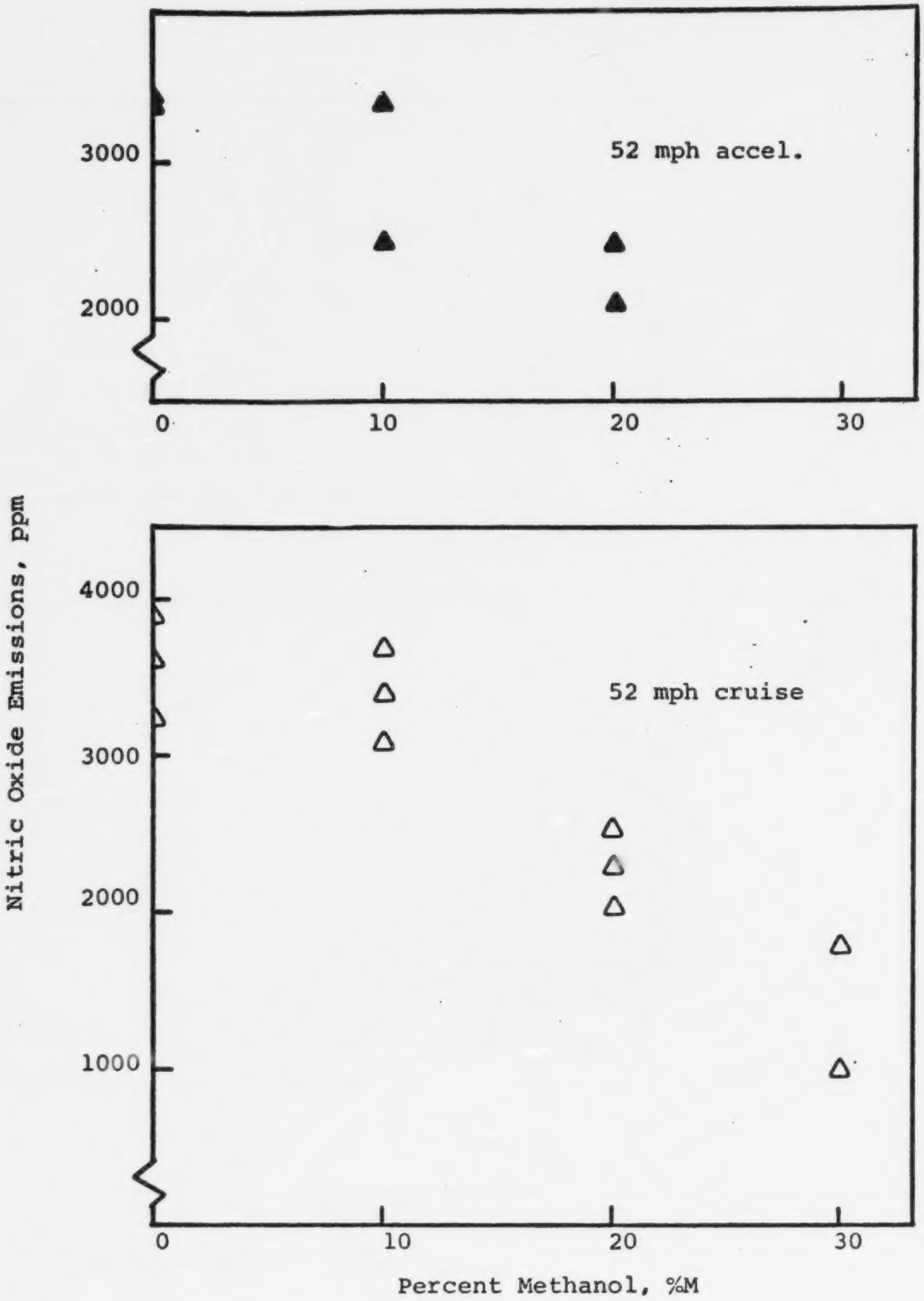


Figure 49b- Illustrates the Reduction in Nitric Oxide Volume Emissions when Methanol Blends are Substituted for Indolene with No Engine Adjustments (Type I Tests)

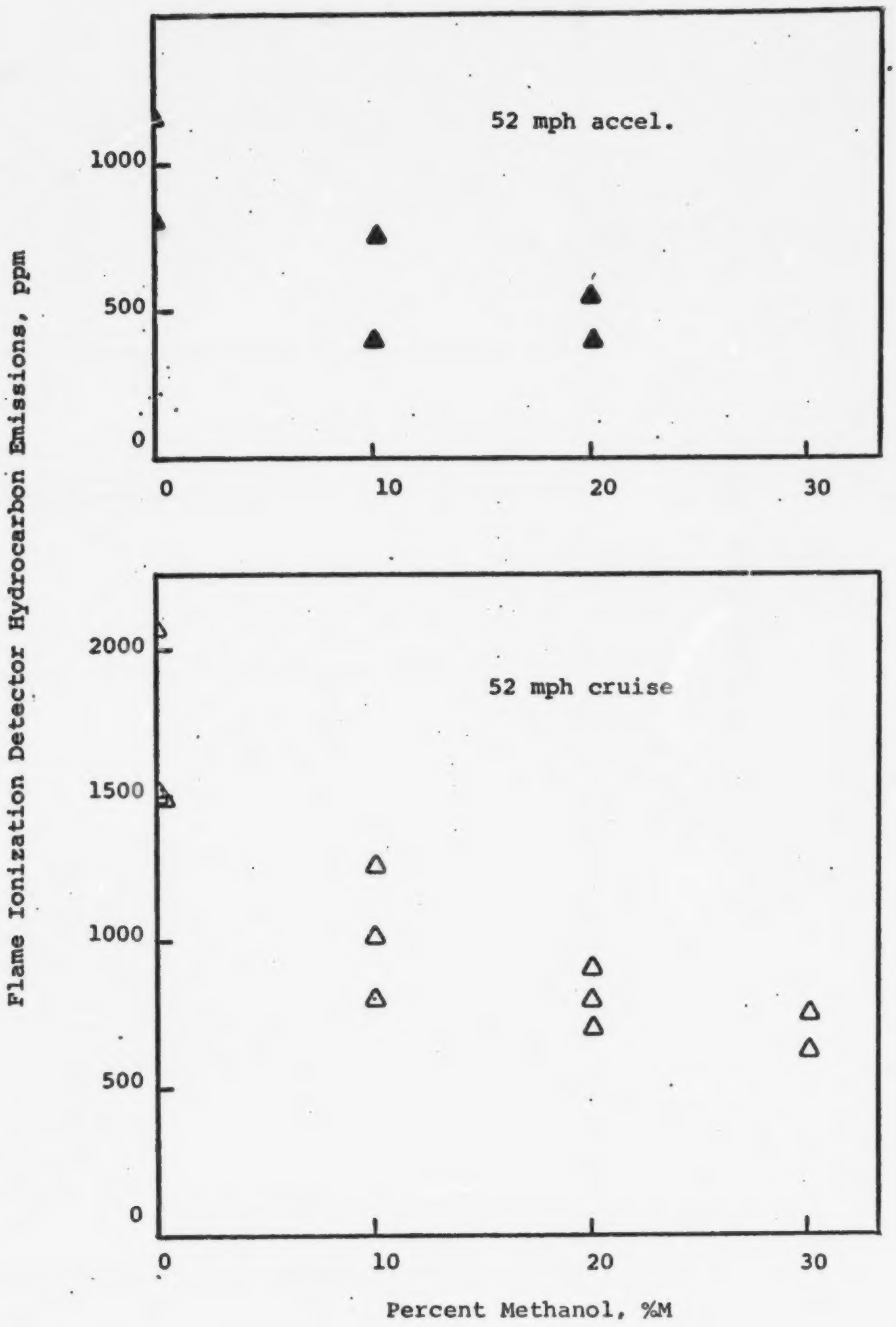


Figure 50a - Illustrates the Reduction in FID HC Volume Emissions when Methanol Blends are Substituted for Indolene with No Engine Adjustments (Type I Tests)

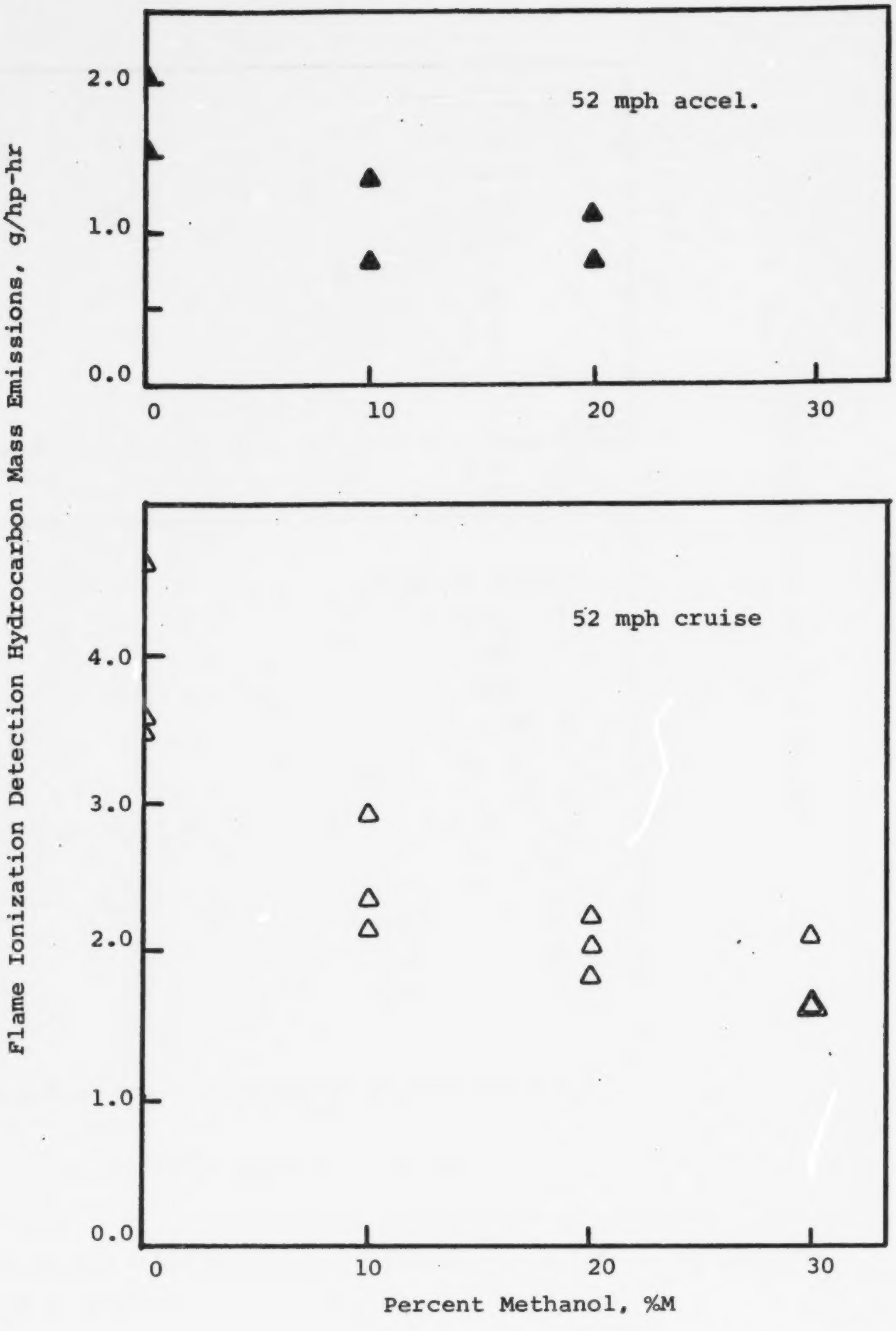


Figure 50b - Illustrates the Reduction in FID HC Mass Emissions when Methanol Blends are Substituted for Indolene with No Engine Adjustments (Type I Tests)

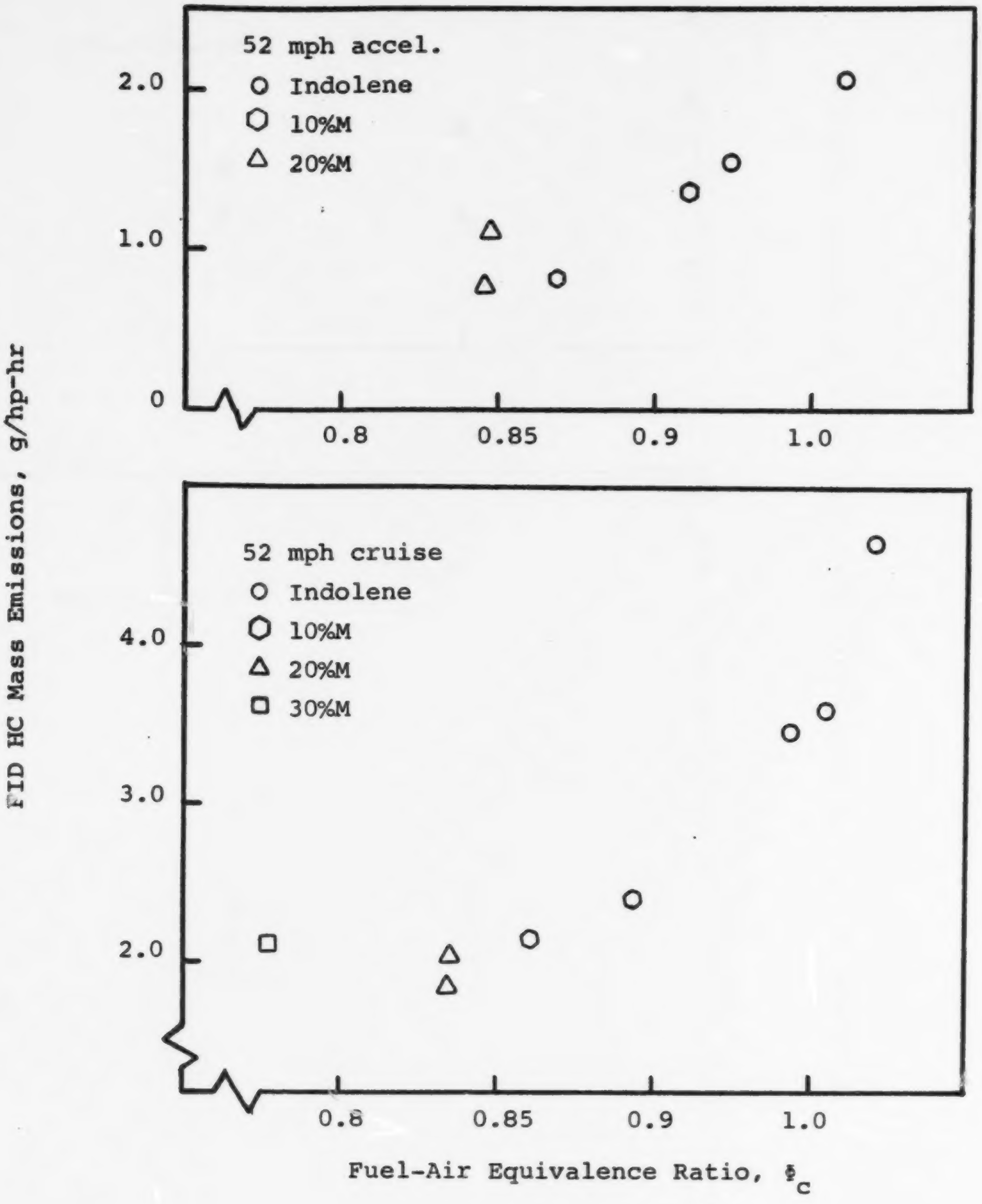


Figure 50c - Shows the Effect of Fuel-Air Equivalence Ratio on FID HC Mass Emissions for the Type I Tests

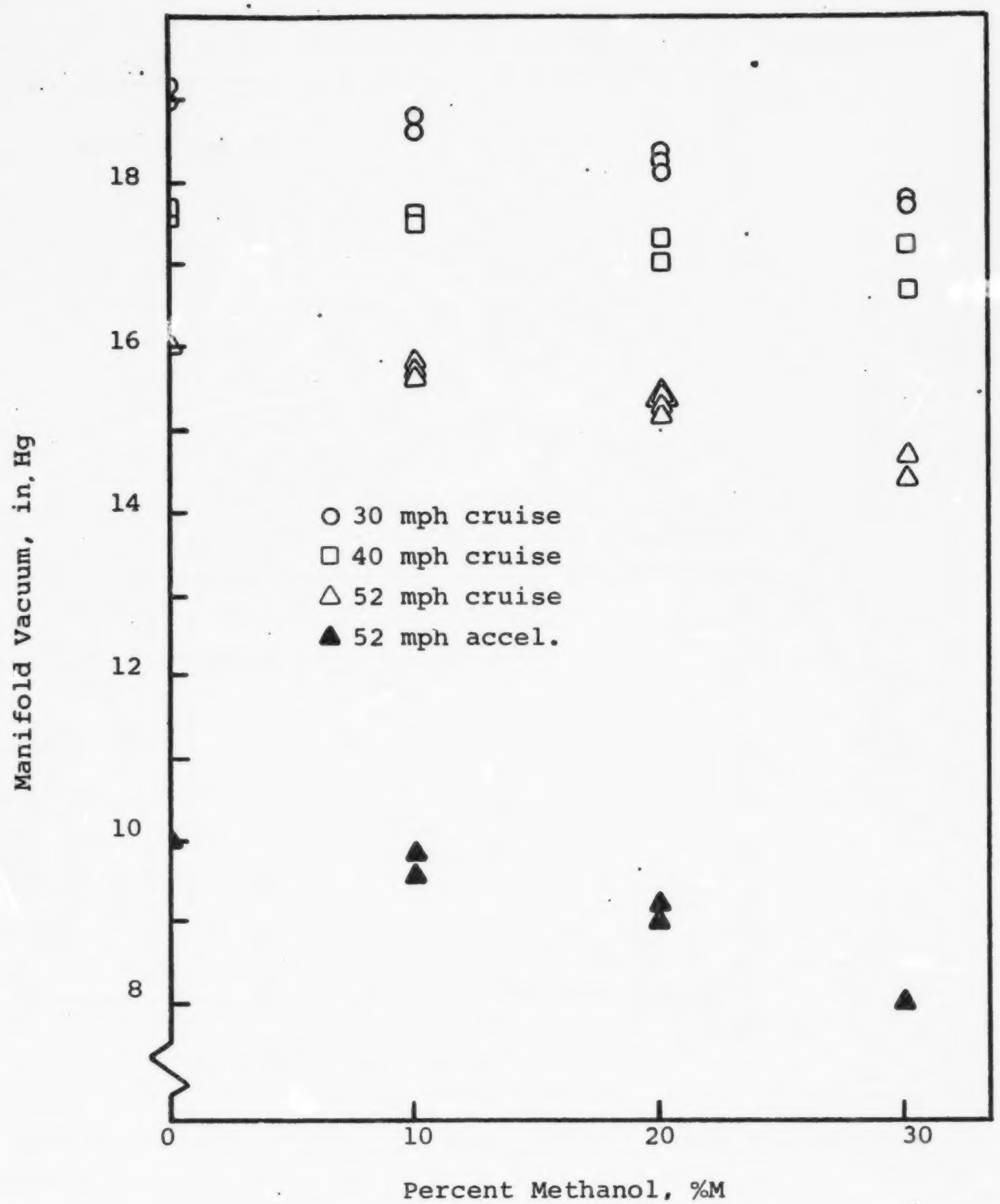


Figure 51 - Shows the Reduced Manifold Vacuum Required for Methanol Blends to Attain the Same Torque and Engine Speed as Found with Indolene (Type II Tests).

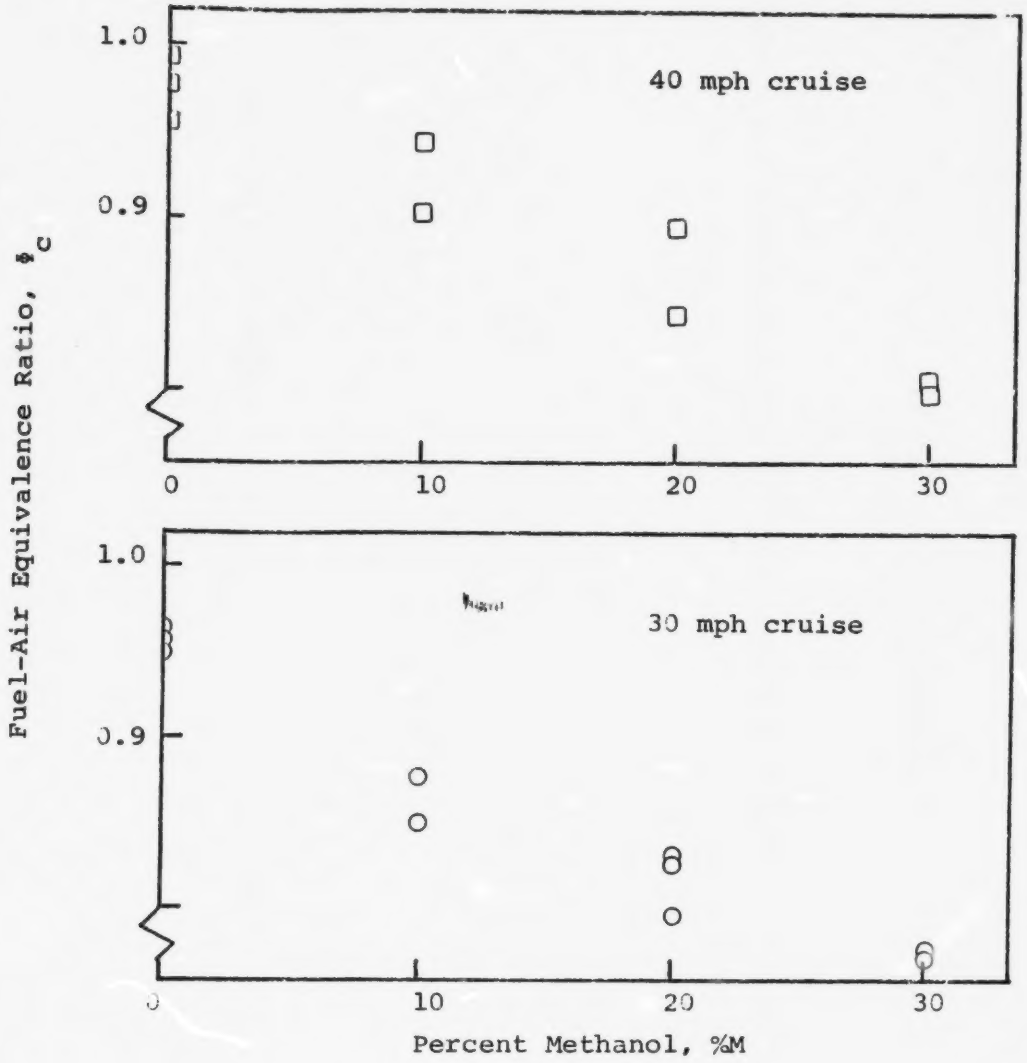


Figure 52 - Shows the Fuel-Air Equivalence Ratio Decrease (Blend Leaning Effect) as a Function of Methanol Blend Level for the Type II Tests

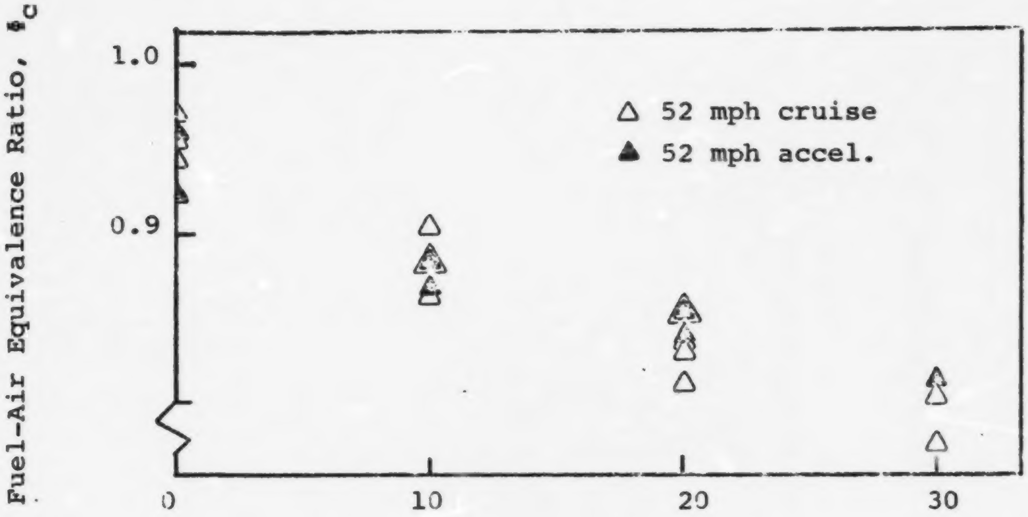


Figure 52 - Shows the Fuel-Air Equivalence Ratio Decrease (cont'd) (Blend Leaning Effect) as a Function of Methanol Blend Level for the Type II Tests

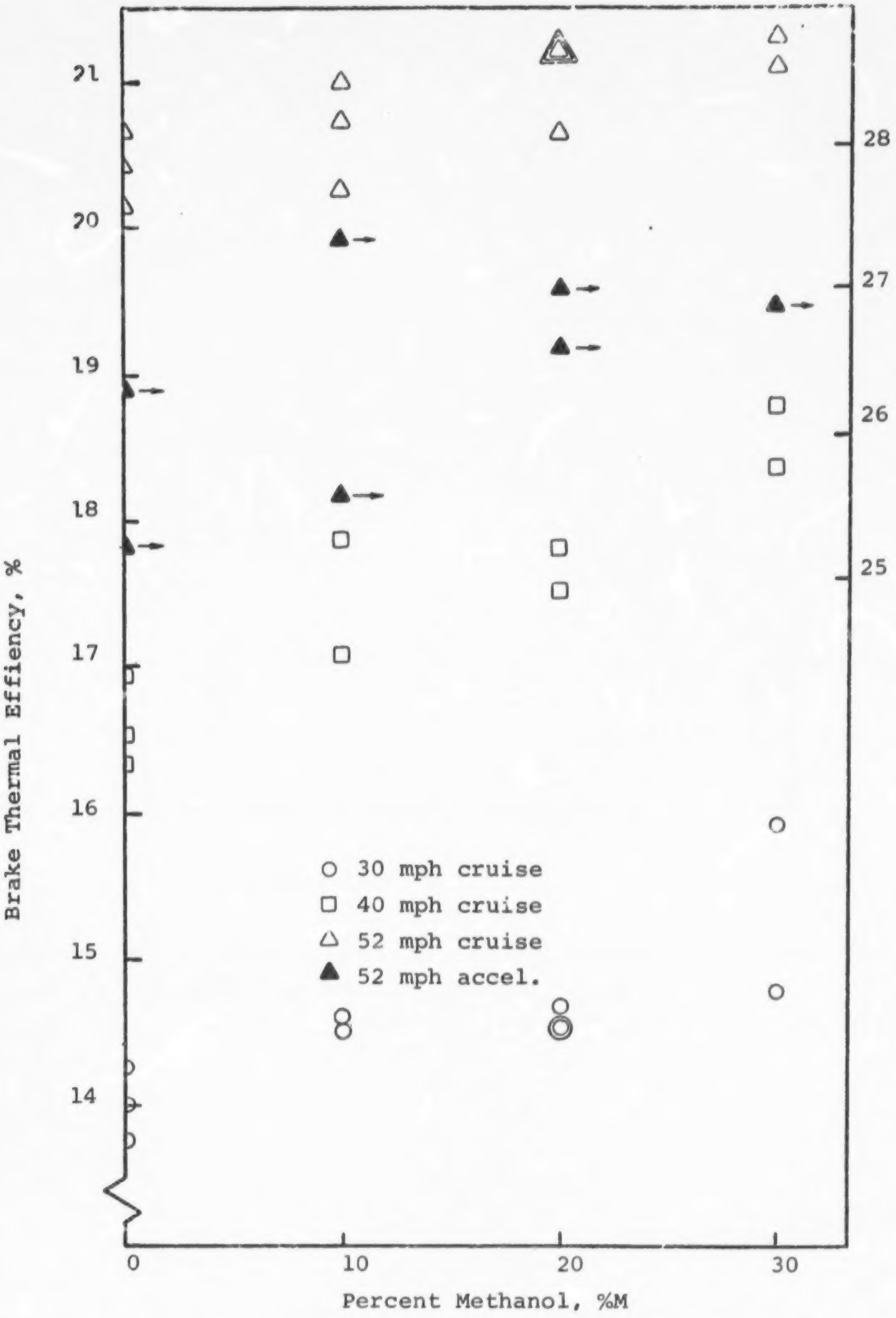


Figure 53 - Shows the Increased Efficiency Obtained with Blends at Equal-to-Indolene Torque and Engine Speed Operation (Type II tests).

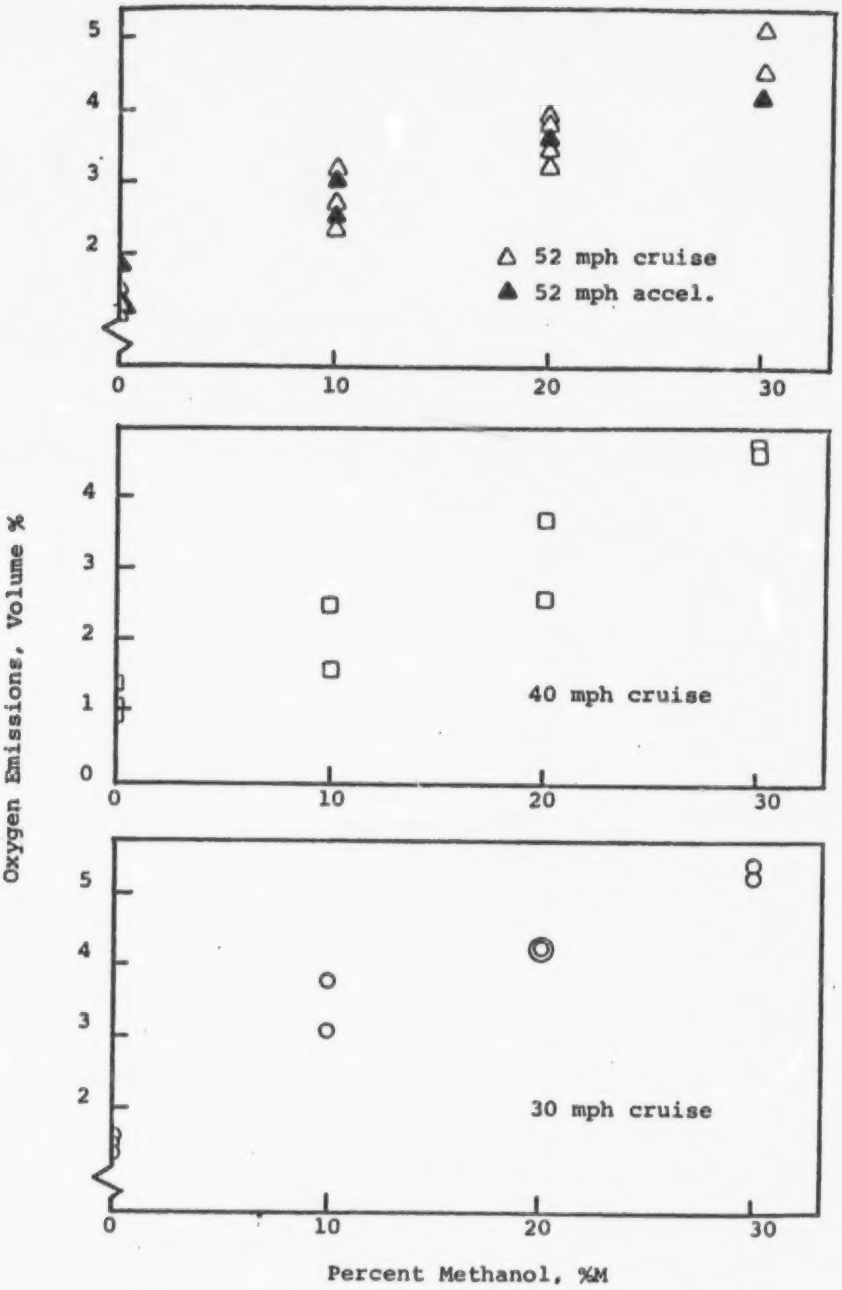


Figure 54 - Shows the Oxygen Emissions as a Function of Methanol Blend Level for the Type II Tests.

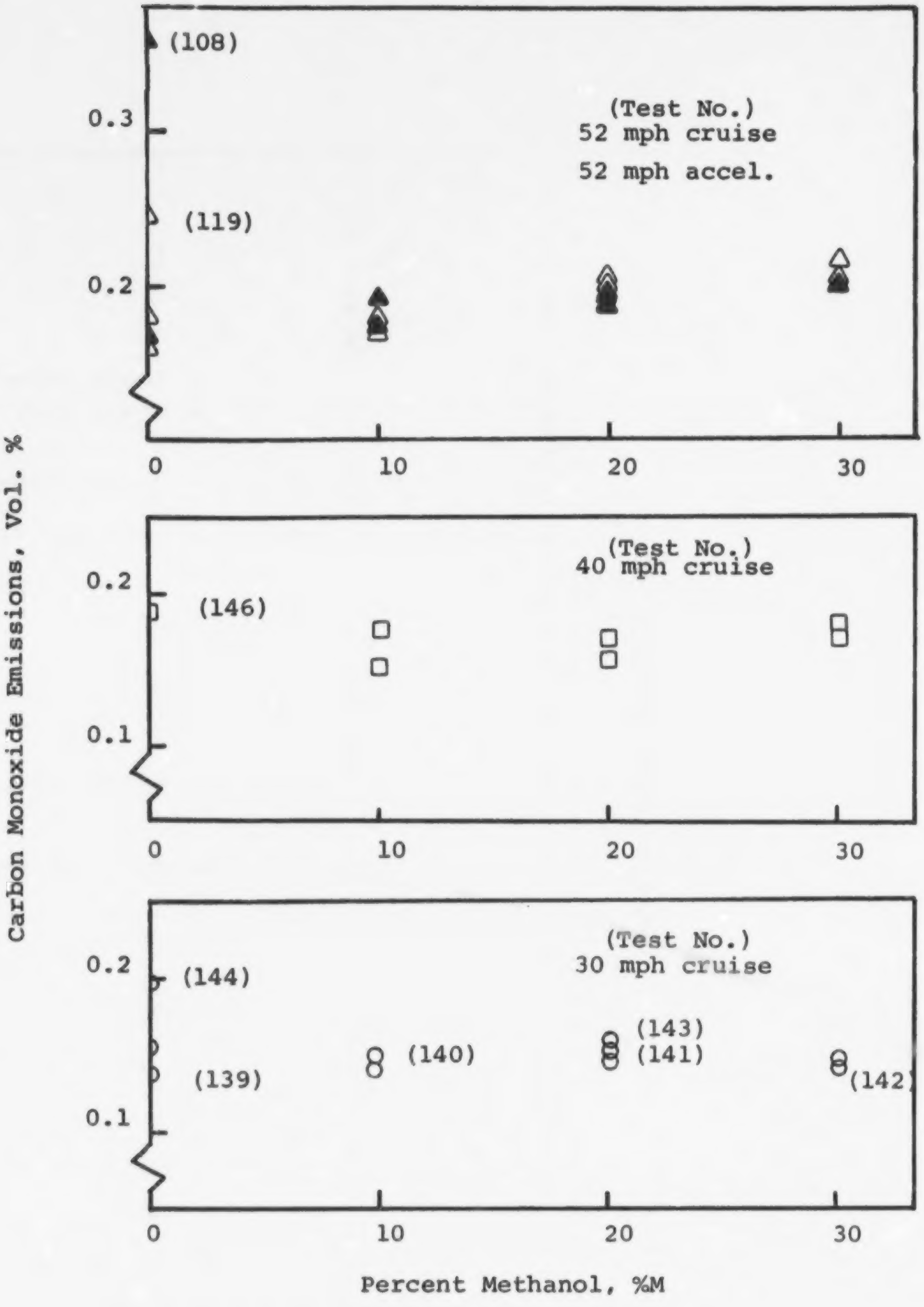


Figure 55a - Shows the Effect of Methanol Addition on CO Volume Emissions at Equal-to-Gasoline Fueled Torque and Engine Speed (Type II Tests)

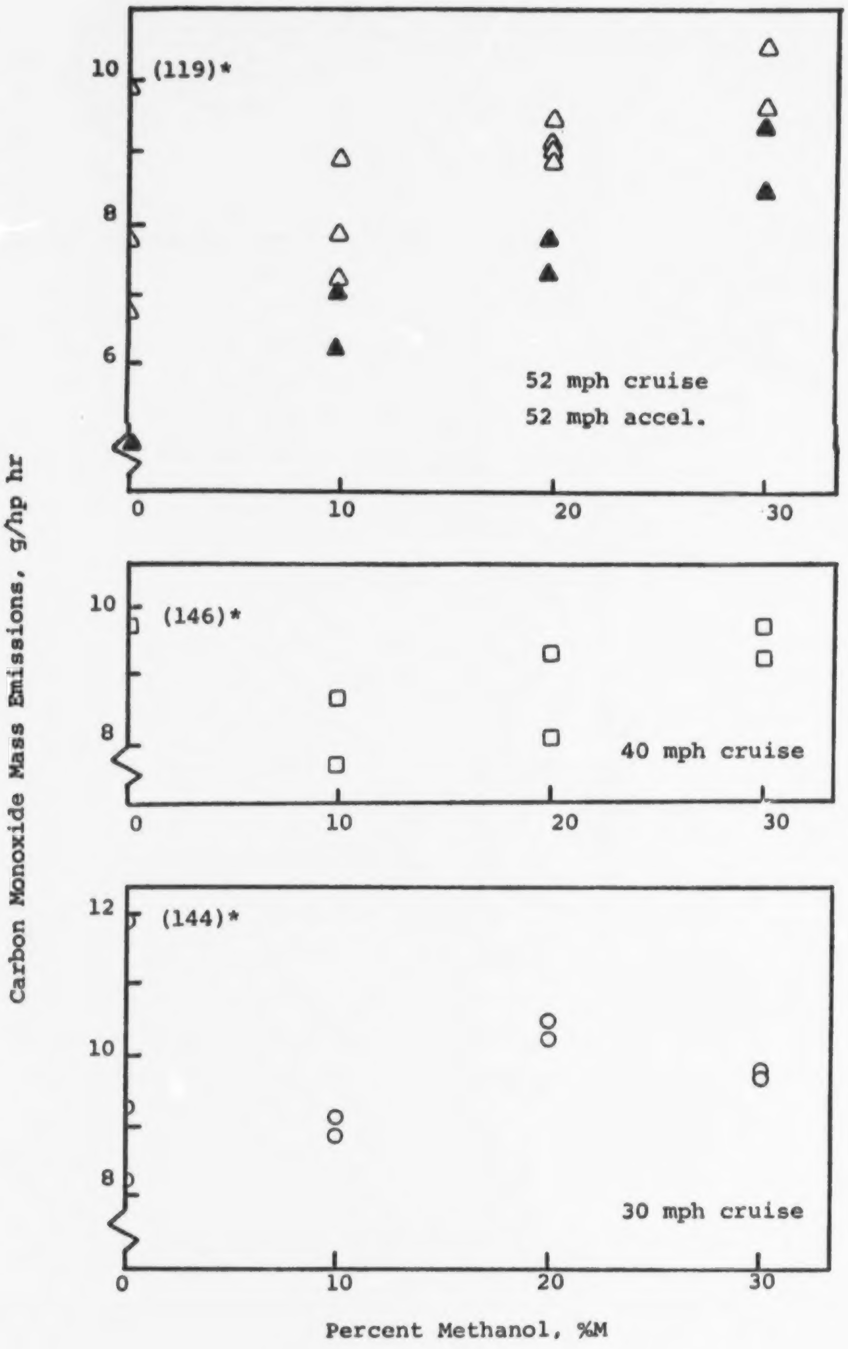


Figure 55b - Shows the Effect of Methanol Addition on CO Mass Emissions at Equal-to-Gasoline Fueled Torque and Engine Speed (Type II Tests)

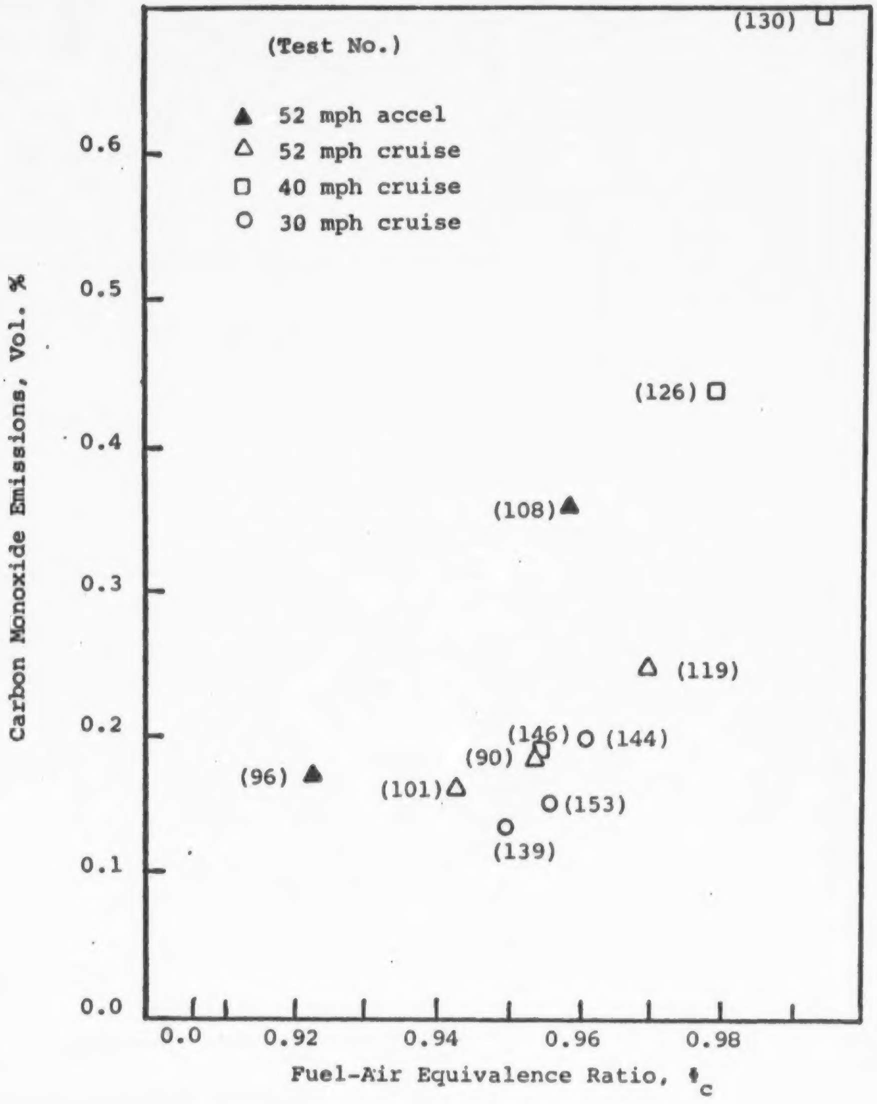


Figure 56a– Illustrates the Effect of Fuel-Air Equivalence Ratio on the CO Volume Emissions for the 0%M Type II Tests

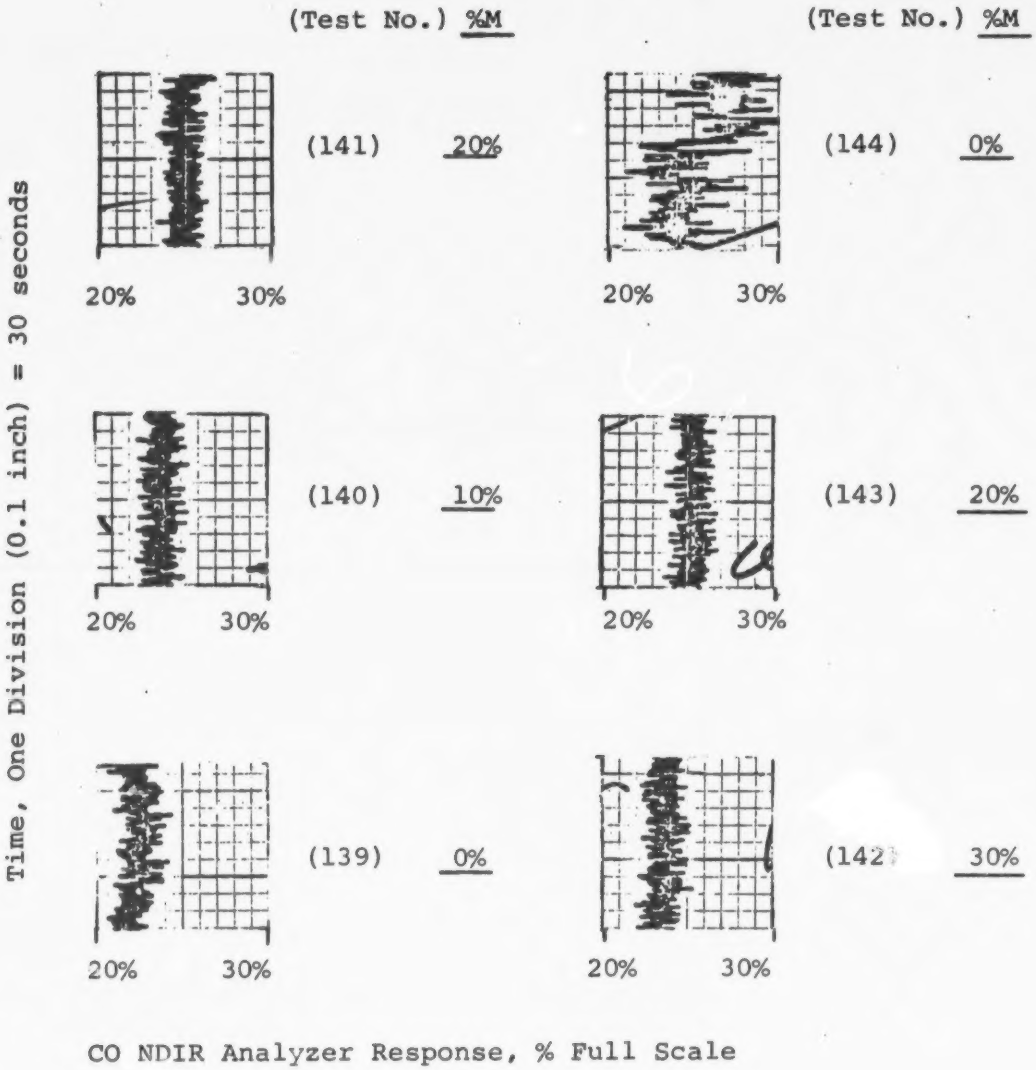


Figure 56b- Shows the CO NDIR Analyzer Response for Tests Numbered 139 through 144 (Type II Tests)

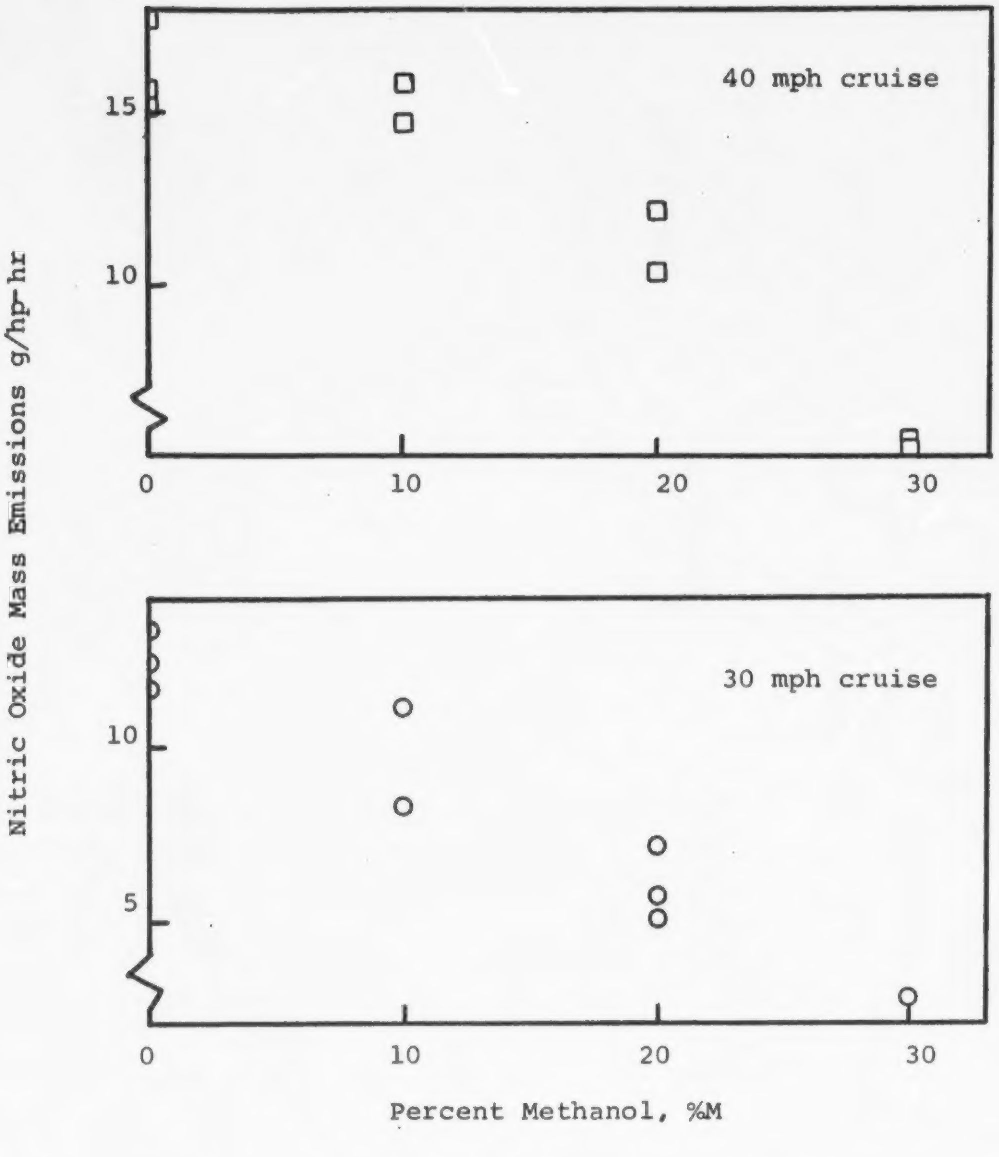


Figure 57 - Illustrates the Reduction in Nitric Oxide Mass Emissions with Methanol Blends at Equal-to-Indolene Torque and Engine Speed Operation (Type II Tests)

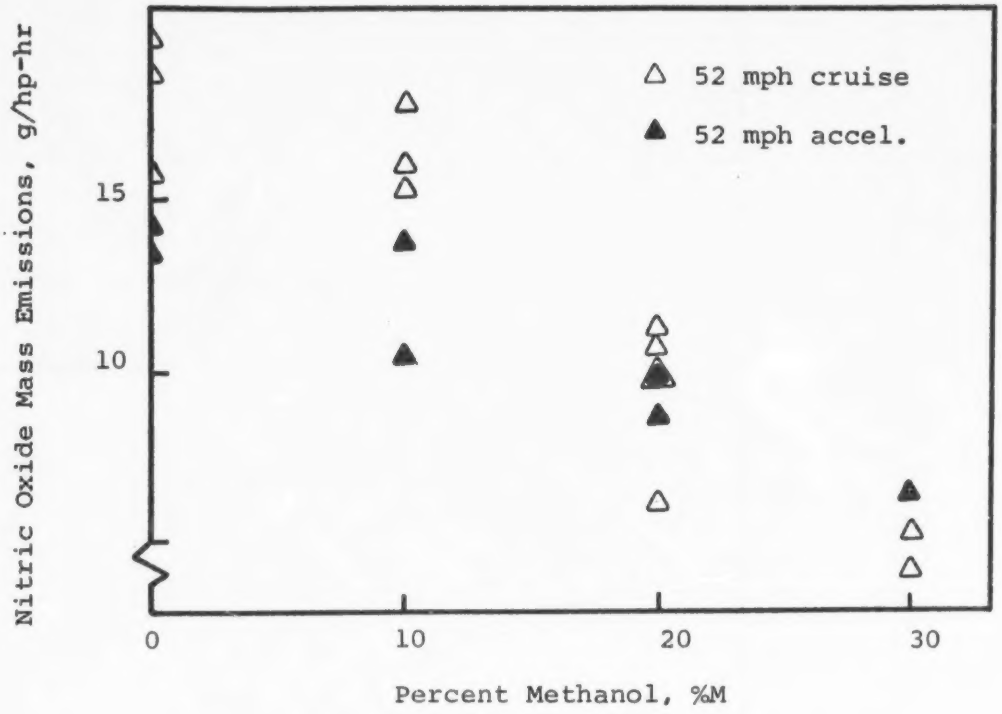


Figure 57 (cont'd) - Illustrates the Reduction in Nitric Oxide Mass Emissions with Methanol Blends at Equal-to-Indolene Torque and Engine Speed Operation (Type II Tests)

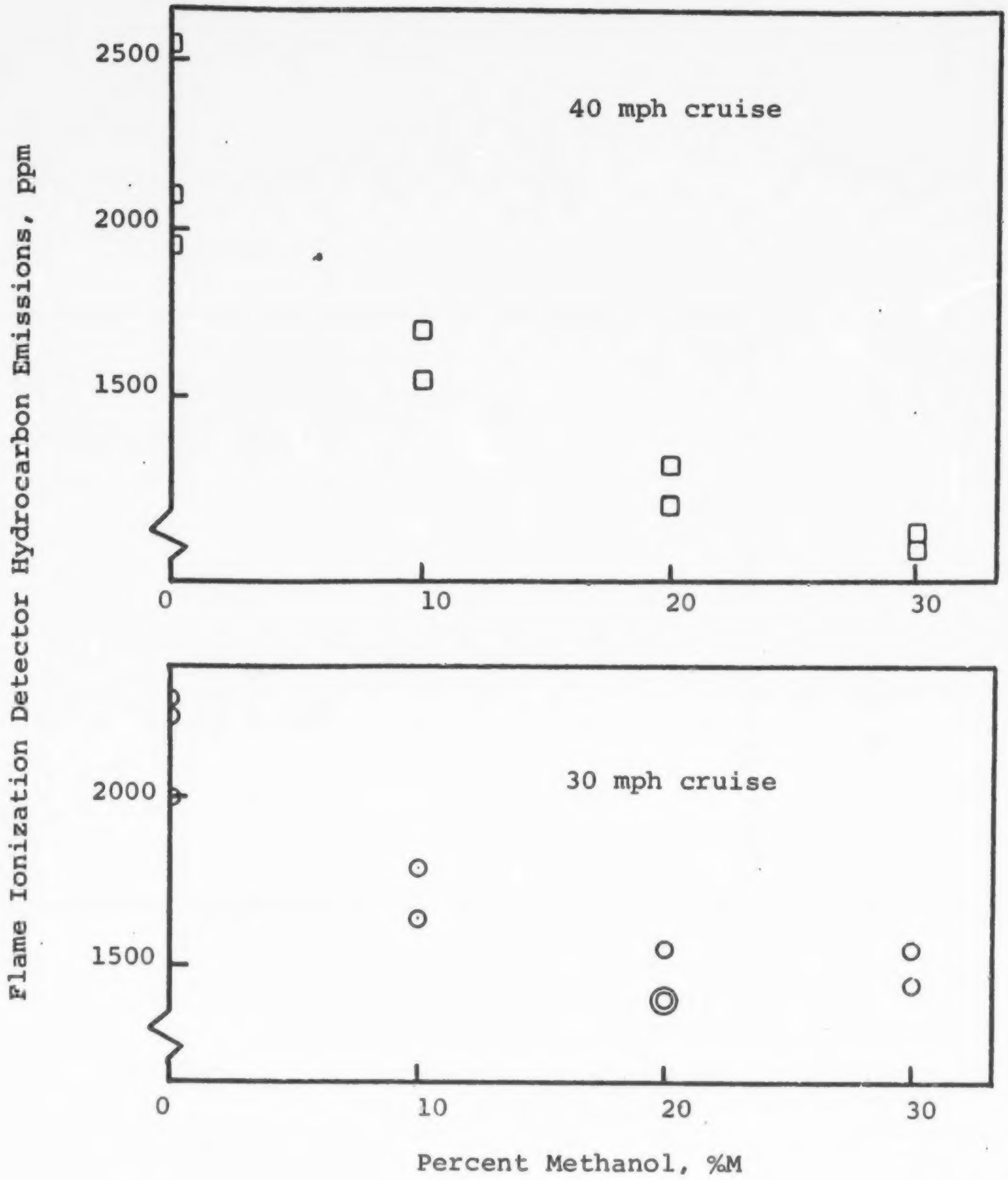


Figure 58a - Illustrates the Reduction in FID HC Volume Emissions with Methanol Blends at Equal-to-Indolene Torque and Engine Speed Operation (Type II Tests).

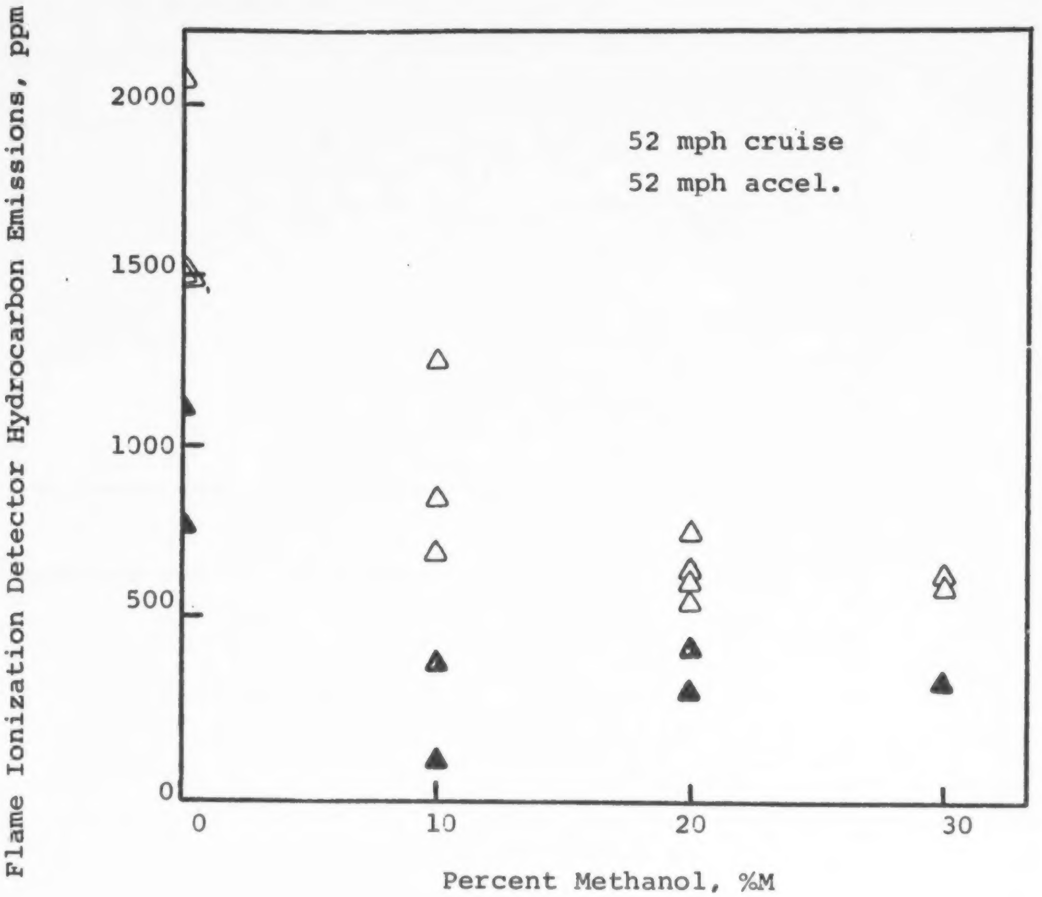


Figure 58a - Illustrates the Reduction in FID HC Volume Emissions (cont'd) with Methanol Blends at Equal-to-Indolene Torque and Engine Speed Operation (Type II Tests)

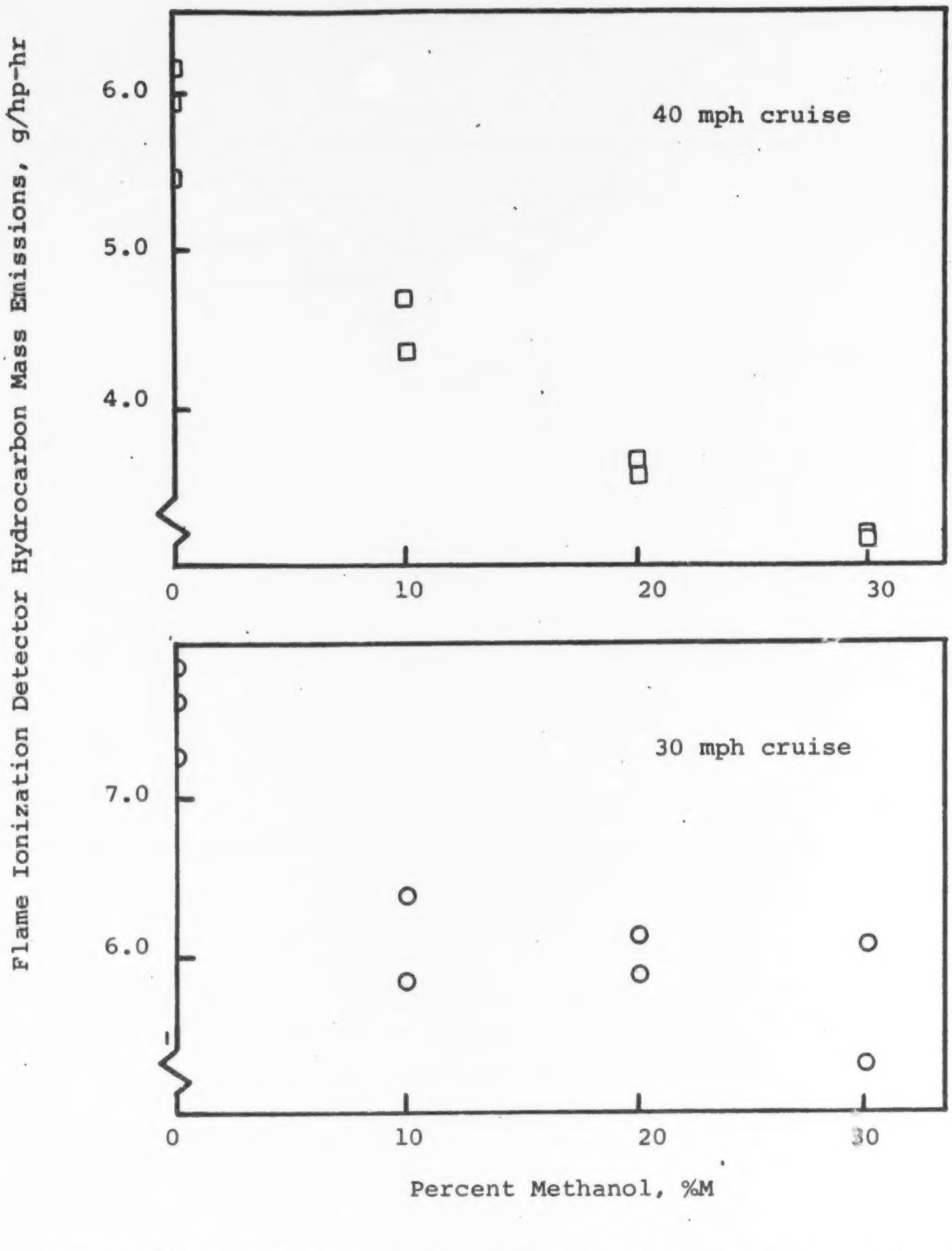


Figure 58b - Illustrates the Reduction in FID HC Mass Emissions with Methanol Blends at Equal-to-Indolene Torque and Engine Speed Operation (Type II Tests)

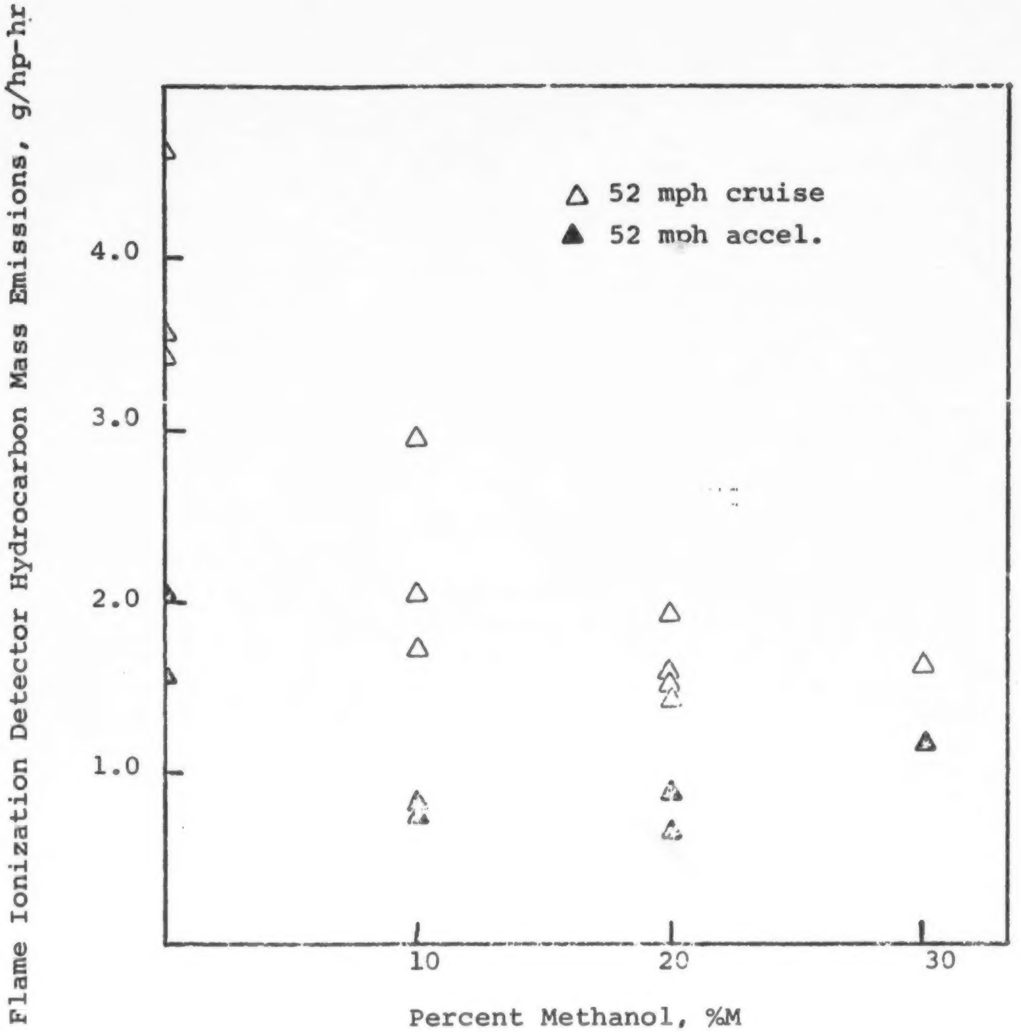


Figure 58b - Illustrates the Reduction in FID HC Mass Emissions
(cont'd) with Methanol Blends at Equal-to-Indolene Torque
and Engine Speed Operation (Type II Tests)

APPENDIX A

ANALYSIS OF EXHAUST GAS

APPENDIX A - ANALYSIS OF EXHAUST GAS

In this Appendix equations are developed (or given) which were used to determine fuel-air equivalence ratios and exhaust mass emissions from exhaust gas concentration measurements. To this end consider the combustion with air of one mole of a fuel blend composed of f moles of methanol (CH_3OH) and (1 - f) moles of hydrocarbon C_XH_Y. The chemical equation representing this combustion process may be expressed in the following form:

$$(1-f)\ C_XH_Y + f\ CH_3OH + n\ O_2 + 3.76\ n\ N_2 \longrightarrow$$

$$(H_2O)_W\ N_W\ H_2O + (CO_2)_D\ N_D\ CO_2 + (CO)_D\ N_D\ CO +$$

$$(O_2)_D\ N_D\ O_2 + (C_AH_B)_W\ N_W\ C_AH_B + (NO)_W\ N_W\ NO +$$

$$(H_2)_W\ N_W\ H_2. \qquad \text{(A1)}$$

In Equation (A1), (i) is the molar concentration of species i. The subscript D identifies those species whose concentrations were determined after the exhaust sample had been dehumidified by passing it through a refrigerated condenser; subscript W identifies those species whose concentrations were determined in a wet sample which was heated to prevent exhaust-gas water condensation. N_W is the total number of moles in the wet sample per mole of fuel blend and N_D is the total number of dry moles per mole of fuel blend.

In Equation (A1) the unburned hydrocarbons are considered to be C_AH_B. If the total hydrocarbon content is expressed in terms of an equivalent carbon content such as would be measured with a flame ionization detector (FID) then for a FID calibration gas C_pH_q (neglecting differences in FID relative hydrocarbon response):

$$A\ (C_AH_B) = p\ (C_pH_q)\ . \qquad \text{(A2)}$$

During the present investigation methane, CH_4, was used as the FID calibration gas. Thus, in the following equations (CH_4) rather than $A(C_AH_B)$ will appear.

Conservation of mass applied to the carbon, hydrogen and oxygen atoms yields the following three Equations:

$$(1-f)X + f = (CO_2)_D N_D + (CO)_D N_D + (CH_4)_W N_W \tag{A3}$$

$$(1-f)Y + 4f = 2(H_2O)_W N_W + 4(CH_4)_W N_W + 2(H_2)_W N_W \tag{A4}$$

$$\begin{aligned} 2n + f = {} & (H_2O)_W N_W + 2(CO_2)_D N_D + (CO)_D N_D + \\ & 2(O_2)_D N_D + (NO)_W N_W \quad . \end{aligned} \tag{A5}$$

From the definition of N_W and N_D

$$N_W - N_D = (H_2O)_W N_W \quad . \tag{A6}$$

Since the exhaust gas hydrogen content was not measured it is necessary to introduce the equation for chemical equilibrium of the water-gas reaction:

$$K = \frac{(CO)_D \ (H_2O)_W}{(CO_2)_D \ (H_2)_W} \quad , \tag{A7}$$

where K is the equilibrium constant.

The above equations may be combined to yield the following expression for the fuel-air ratio

$$\left(\frac{F}{A}\right) = \frac{137.28 \quad n}{(1-f) \ (12X+Y) + 32f} \tag{A8}$$

where

$$\begin{aligned} n = {} & [(CO_2)_D + 0.5(CO)_D + (O_2)_D - 0.5]N_D \\ & + [0.5 \ (1 + (NO)_W)]N_W - f/2 \quad , \end{aligned} \tag{A9}$$

$$N_W = \Gamma \ N_D + \delta \quad , \tag{A10}$$

$$N_D = \frac{(1-f)X + f - (CH_4)_W \, \delta}{(CO_2)_D + (CO)_D + (CH_4)_W \, \Gamma} \quad , \qquad (A11)$$

$$\delta = \frac{(1-f)\,(Y/2) + 2f}{\beta \, \Gamma^{-1}} \quad , \qquad (A12)$$

$$\Gamma^{-1} = 1 + \frac{2\,(CH_4)_W}{\beta} \quad , \qquad (A13)$$

and

$$\beta = 1 + \frac{(CO)_D}{K\,(CO_2)_D} \quad , \qquad (A14)$$

In arriving at Equation (A8) the molecular weight of oxygen and nitrogen were taken to be 32 and 28 respectively. For the present investigation the base fuel was Indolene with X = 7 and Y = 13.02. A value of 3.8 was assigned to the water-gas equilibrium constant K.

To determine the fuel-air equivalence ratio,

$$\phi_c = \frac{F/A}{(F/A)\ \text{STOICH.}} \quad , \qquad (A15)$$

the following equation, taken from Reference (3), was used to calculate the stoichiometric fuel-air ratio:

$$\left(\frac{F}{A}\right)_{\text{STOICH.}} = \frac{97.02 - 65.02\,f}{1407.81 - 1201.89\,f} \quad . \qquad (A16)$$

The above equations are in terms of methanol mole fraction f. During the experiments the various methanol blends were mixed on a volume basis as is described in Section II. B. Equation (A17) gives the relation between mole fraction and mass fraction, mf, (3):

$$f = \frac{97.02\ mf}{65.02\ mf + 32} \quad . \qquad (A17)$$

The mass fraction in turn is related by Equation (A18) to the volume fraction of methanol, %M, (3):

$$\mathrm{mf} = \frac{\%M}{\%M + 0.93\ (100 - \%M)} \quad . \tag{A18}$$

In Equation (A18) the specific gravity of Indolene is taken to be 0.74; for methanol 0.796.

The following equations, from Reference (3), were used to calculate the mass emissions:

$$\mathrm{gm\ HC/HP{\cdot}hr} = 16\ Z\ (CH_4)_W\ N_W/N_D \tag{A19}$$

$$\mathrm{gm\ CO/HP{\cdot}hr} = 28\ Z\ (CO)_D \tag{A20}$$

$$\mathrm{gm\ CO_2/HP{\cdot}hr} = 44\ Z\ (CO_2)_D \tag{A21}$$

$$\mathrm{gm\ NO_x/HP{\cdot}hr} = (14 + 16\ R)\ Z\ (NO_x)_W\ N_W/N_D \tag{A22}$$

where

$$Z = \frac{453.59\ \mathrm{BSFC}\ [(1-f)\ 7 + f]}{[(CO_2)_D + (CO)_D + (CH_4)_W + N_W/N_D][(1-f)(97.02) + 32f]}\ . \tag{A23}$$

In Equation (A22), (14 + 16 R) is the volume-averaged molecular weight of the NO_x emissions where

$$R = \frac{2\ (NO_2) + (NO)}{NO_x} \quad . \tag{A24}$$

APPENDIX B

PERFORMANCE AND EMISSIONS
CHARACTERISTICS PROGRAM

Definitions of Fortran Symbols Used

Fortran Symbol	Text Symbol	Description	Units
A	A	Average Number Carbon Atoms in Exhaust Gas Average Hydrocarbon	---
AFHCF		Air Flow Humidity Correction Factor	---
AFLO	$\dot{m}_A$	Air Mass Flow Rate	lbm/hr
AFPCF		Air Flow Pressure Correction Factor	---
AFR		Air Flow Gauge Reading	in. H_2O
AFTCF		Air Flow Temperature Correction Factor	---
B		Average Number of Hydrogen Atoms in Exhaust Gas Average Hydrocarbon	---
BETA	β	Defined by Equation (A14)	---
BHP	bhp	Brake Horse Power	hp
BP	p_b	Barometric Pressure	in. hg
BSFC	bsfc	Brake Specific Fuel Consumption	lb/hp-hr
BTHE	η_b	Brake Thermal Efficiency	%
CBHP	bhp_c	Corrected Brake Horse Power	hp
CBMEP	bmep_c	Corrected Brake Mean Effective Pressure	psi
CH3OHP	(CH_3OH)	Volume Concentration of Methanol in Exhaust	%
CH4D		HC Volume Concentration in Dry Exhaust Sample	ppm
CH4FD	$(CH_4)_D$	Same as CH4D except Volume Fraction Rather than ppm Units	---
CH4FW	$(CH_4)_W$	HC Volume Fraction Measured by FID in Wet Exhaust Sample	---
CH4OFD	$(CH_3OH)_D$	Methanol Volume Fraction in Dry Exhaust Sample	---

Definitions of Fortran Symbols Used (cont.)

Fortran Symbol	Text Symbol	Description	Units
COFD	$(CO)_D$	CO Volume Fraction in Dry Exhaust Sample	---
COM		CO Mass Emissions	g/hp-hr
COP	CO	Volume Percent CO in Dry Exhaust Sample	%
COR		CO Analyzer Meter Reading	---
CO2FD	$(CO_2)_D$	CO_2 Volume Fraction in Dry Exhaust Sample	---
CO2M		CO_2 Mass Emissions	g/hp-hr
CO2P	CO_2	Volume Concentration CO_2 in Exhaust	%
CO2R		CO_2 Analyzer Meter Reading	---
CTI		Coolant Inlet Temperature	°F
CTIV		Coolant Inlet Thermocouple EMF	mv
CTO		Coolant Outlet Temperature	°F
CTOV		Coolant Outlet Thermocouple EMF	mv
D	D	Engine Displacement	cu in.
DATE		Date the Test Point was Run	---
DBT	T_{db}	Dry Bulb Temperature	°F
DELTA	δ	Defined By Equation (A12)	---
EP	P_{ex}	Exhaust Pressure	psi
ER	Φ_m	Fuel-Air Equivalence Ratio Determined from Fuel and Air Mass Flow Measurements	---
ERCHM	Φ_c	Fuel-Air Equivalence Ratio Determined from Chemical Analysis (Appendix A)	---
ETV1		Exhaust Thermocouple EMF Cyl. No. 1	mv
ETV2		Exhuast Thermocouple EMF Cyl. No. 2	mv
ETV3		Exhaust Thermocouple EMF Cyl. No. 3	mv
ETV4		Exhaust Thermocouple EMF Cyl. No. 4	mv

Definitions of Fortran Symbols Used (cont.)

Fortran Symbol	Text Symbol	Description	Units
ET1		Exhaust Temperature Cylinder No. 1	$^{\circ}F$
ET2		Exhaust Temperature Cylinder No. 2	$^{\circ}F$
ET3		Exhaust Temperature Cylinder No. 3	$^{\circ}F$
ET4		Exhaust Temperature Cylinder No. 4	$^{\circ}F$
F	f	Mole Fraction of Methanol in the Fuel Blend	---
FAC	$(F/A)_c$	Fuel-Air Ratio Determined from Chemical Analyses (Appendix A)	---
FARS	FA	Stoichiometric Fuel-Air Ratio	---
FF	$\dot{m}_f$	Fuel Mass Flow Rate	lb/hr
FFR		Fuel Flow Rotameter Reading	---
GAMMA	Γ	Defined by Equation (A13)	---
HC	HC	Volume Concentration of HC in Exhaust	ppm
HCHOFD	$(HCHO)_D$	Formaldehyde Volume Fraction in Dry Exhaust Sample	---
HCHOP	HCHO	Volume Percent of Formaldehyde in Exhaust	%
HCM	HC	Hydrocarbon Mass Emissions	g/hp-hr
HPCF		Horse Power Correction Factor	---
I		Internal Step Counter (I=1, First Data Point; I=2, Second Data Point...)	---
J		Range of the CO Analyzer (Lo 1, Jn=1; Lo 3, Jn=2; Hi 1, Jn=3; Hi 2, Jn=4)	---
JN		Intermediate CO Range Selection Index (Lo 1, Jn=1; Lo 3, Jn=2; Hi 1, Jn=3; Hi 2, Jn=4)	---

Definitions of Fortran Symbols Used (cont.)

Fortran Symbol	Text Symbol	Description	Units
L		Intermediate Air Flow Meter Nozzle Size Selection Index (Nozzle Size = 0.5 in Diameter, L=1; 0.75 in, L=2; 1.183 in, L=3; 1.75 in, L=4; 2.75 in, L=5; 4.5 in, L=6)	---
M		Intermediate Base Fuel Selection Index (M=1, Indolene; M=2, Isooctane)	---
NBFUEL		Base Fuel Index (I or In=1, Indolene; I or In=2, Isooctane)	---
NS		Same as L	---
NTEST		Test Number	---
OP		Oil Pressure	psi
O2FD	$(O_2)_D$	Oxygen Volume Fraction in Dry Exhaust Sample	---
O2M		O_2 Mass Emissions	g/hp-hr
O2P		Volume Percent of O_2 in Exhaust	%
PM	%M	Volume Concentration of Methanol in Blend	%
RATWD	Nw/Nd	Ratio of the Number of Wet to Dry Moles of Exhaust	---
RK	R	Average Number of O Atoms in NO_X Defined by Equation (A24)	---
RLHVB		Lower Heating Value of the Blend	BTU/lb_m
RLHVG		Lower Heating Value of the Base Fuel	BTU/lb_m
RLHVM		Lower Heating Value of Methanol	BTU/lb_m
RMF	mf	Mass Fraction of Methanol in the Blend	---
RMV	P_{man}	Manifold Vacuum	in.Hg
RN	N	Engine Speed	rpm
RND	N_D	Number of Moles of Dry Exhaust per Mole of Fuel	---

Definitions of Fortran Symbols Used (cont.)

Fortran Symbol	Text Symbol	Description	Units
RNO	NO	Volume Concentration of NO in Exhaust	ppm
RNOX		NO_X Concentration of NO_X in Exhaust	ppm
RNOXD	NO_X	NO_X Volume Concentration in Dry Exhaust	ppm
RNOXFD	$(NO_X)_D$	Same as RNOXD Except units are Volume Fraction	---
RNOXFW	$(NO_X)_W$	NO_X Volume Fraction in Wet Exhaust	---
RNOXM		NO_X Mass Emissions	g/hp-hr
RNO2	NO_2	Volume Concentration NO_2 in Exhaust	ppm
RNW	N_W	Number of Moles of Wet Exhaust per Mole of Fuel	---
RRK	K	Water-gas Reaction Equilibrium Constant [See Equation (A7)]	---
RRN	n	Number of Moles of Exygen per Mole of Fuel Blend in Fresh Charge [See Equation (A1)]	---
SA	SA	Spark Advance	^{o}BTDC
SGB	γ_B	Specific Gravity of the Blend	---
SGG	γ_G	Specific Gravity of the Base Fuel	---
SGM	γ_M	Specific Gravity of the Methanol	---
T	T	Torque	ft-lb_f
TET		Total Engine Time	hr
TIMV1		Intake Port Thermocouple EMF Cylinders 1 and 2	mv
TIMV2		Room Air Thermocouple EMF	mv
TIMV3		Intake Port Thermocouple EMF Cylinders 3 and 4	mv
TIMV4		Carburetor Base Thermocouple EMF	mv

Definitions of Fortran Symbols Used (cont.)

Fortran Symbol	Text Symbol	Description	Units
TIM1		Intake Port Temperature, Cylinders 1 and 2	$^\circ F$
TIM2		Room Air Temperature	$^\circ F$
TIM3		Intake Port Temperature, Cylinders 3 and 4	$^\circ F$
TIM4		Carburetor Base Temperature	$^\circ F$
VE	η_v	Volumetric Efficiency	%
WBT	T_{wb}	Wet Bulb Temperature	$^\circ F$
X	X	Number of Carbon Atoms in Base Fuel	---
XX1 - XX11		Intermediate Calculation Steps Used in Chemical Analysis Equations of Appendix A	---
Y	Y	Number of Hydrogen Atoms in Base Fuel	---

```
MEN*METHANOL(1).GASM2 FOR CREATED ON 7 FEB 78 AT 12:10:47
@FOR,IS
C     DATA REDUCTION PROGRAM FOR THE CHARACTERIZATION OF METHANOL-GASOLI
C    *NE BLENDS AS AN AUTOMOTIVE FUEL
C     DIMENSION THE ONE DIMENSIONAL MATRICIES.
    5 DIMENSION NTEST(10),NBFUEL(10),J(10),NS(10),DATE(10),PM(10),DBT(10
     *),WBT(10),SP(10),FFR(10),AFR(10),TET(10),CTIV(10),CTOV(10),OP(10),
     *EP(10),RMV(10),SA(10),RN(10),T(10),COR(10),O2P(10),RNO(10),RNO2(10
     *),RNOX(10),HC(10),CO2R(10),CH3OHP(10),HCHOP(10),ETV1(10),ETV2(10),
     *ETV3(10),ETV4(10),TIMV1(10),TIMV2(10),TIMV3(10),TIMV4(10)
C     DIMENSION THE RESULTS
   10 DIMENSION ER(10),FARS(10),CBHP(10),BSFC(10),CBMEP(10),VE(10),BTHE(
     *10),COP(10),CO2P(10),O2M(10),COM(10),CO2M(10),RNOXM(10),HCM(10),AF
     *LD(10),FF(10),CTI(10),ET1(10),ET2(10),ET3(10),ET4(10),TIM1(10),TIM
     *2(10),TIM3(10),TIM4(10),CTO(10),RND(10),RATWD(10),ERCHM(10),CH4D(1
     *0),RNOXD(10)
C     SET I = TO ONE.
    7 I=1
C     READ THE DATA CARDS, 10 ITEMS TO A CARD, 8 SPACES EACH ITEM.
   20 READ(5,15)NTEST(I),NBFUEL(I),J(I),NS(I),DATE(I),PM(I),DBT(I),WBT(I
     *),SP(I),FFR(I),AFR(I),TET(I),CTIV(I),CTOV(I),OP(I),EP(I),RMV(I),SA
     *(I),RN(I),T(I)
   15 FORMAT(4I9,6F8.4/10F8.3)
      IF (NTEST(I).LT.0) GO TO 999
   30 READ(5,35)COR(I),O2P(I),RNO(I),RNO2(I),RNOX(I),HC(I),CO2R(I),CH3OH
     *P(I),HCHOP(I),ETV1(I),ETV2(I),ETV3(I),ETV4(I),TIMV1(I),TIMV2(I),TI
     *MV3(I),TIMV4(I)
   35 FORMAT(10F8.3/7F8.4)
C     DEFINE THE CONSTANTS TO BE USED IN THE CALCULATIONS.
   40 A=7.0
   41 B=13.02
   45 SGM=0.796
   50 RLHVM=8644.0
   55 D=197.0
   60 RR=((2.0*RNO2(I))+RNO(I))/RNOX(I)
   61 IF(RR.LT.1.0)RR=1.0
C     DETERMINE BASE FUEL AND VALUES ASSOCIATED WITH IT.
   65 M=NBFUEL(I)
   70 GO TO(75,85),M
   75 SGG=0.74
   76 X=7.0
   77 Y=13.02
   78 RLHVG=19000.0
   79 GO TO 90
   85 SGG=0.692
   86 X=8.0
   87 Y=18.0
   88 RLHVG=19060.0
C     DETERMINE THE MASS AND MOLE FRACTIONS OF METHANOL IN THE BLEND.
   90 RMF=(PM(I)/100.0)/(PM(I)/100.0+(1.0-PM(I)/100.0)*(SGG/SGM))
   91 TIM1(I)=29.036+45.73*TIMV1(I)-0.136*TIMV1(I)**2.0+0.002*TIMV1(I)**
     *3.0
   92 TIM2(I)=29.036+45.73*TIMV2(I)-0.136*TIMV2(I)**2.0+0.002*TIMV2(I)**
     *3.0
   93 TIM3(I)=29.036+45.73*TIMV3(I)-0.136*TIMV3(I)**2.0+0.002*TIMV3(I)**
     *3.0
   94 TIM4(I)=29.036+45.73*TIMV4(I)-0.136*TIMV4(I)**2.0+0.002*TIMV4(I)**
```

```
     *3.0
   95 F=(RMF*12.0*X+RMF*Y)/(-32.0*RMF+12.0*X*RMF+Y*RMF+32.0)
   96 ET1(I)=29.036+45.73*ETV1(I)-0.136*ETV1(I)**2.0+0.002*ETV1(I)**3.0
   97 ET2(I)=29.036+45.73*ETV2(I)-0.136*ETV2(I)**2.0+0.002*ETV2(I)**3.0
   98 ET3(I)=29.036+45.73*ETV3(I)-0.136*ETV3(I)**2.0+0.002*ETV3(I)**3.0
   99 ET4(I)=29.036+45.73*ETV4(I)-0.136*ETV4(I)**2.0+0.002*ETV4(I)**3.0
C      CALCULATE THE AIR FLOW TEMP.+ PRESS. + HUM. CORR. FACTORS
  100 AFPCF=0.0166*BP(I)+0.5028
  101 AFTCF=(-0.00095)*DBT(I)+1.057
  102 IF(WBT(I).GT.52.49.AND.WBT(I).LT.57.5)AFHCF=((DBT(I)-55.0)*0.0004)
     *+0.989
  103 IF(WBT(I).GT.57.49.AND.WBT(I).LT.62.5)AFHCF=((DBT(I)-60.0)*0.0004)
     *+0.985
  104 IF(WBT(I).GT.62.49.AND.WBT(I).LT.67.5)AFHCF=((DBT(I)-65.0)*0.0004)
     *+0.979
  105 IF(WBT(I).GT.67.49.AND.WBT(I).LT.72.5)AFHCF=((DBT(I)-70.0)*0.0004)
     *+0.975
  106 IF(WBT(I).GT.72.49.AND.WBT(I).LT.77.5)AFHCF=((DBT(I)-75.0)*0.0004)
     *+0.971
  107 IF(WBT(I).GT.77.49.AND.WBT(I).LT.82.5)AFHCF=((DBT(I)-80.0)*0.0004)
     *+0.966
  108 CTI(I)=29.036+45.73*CTIV(I)-0.136*CTIV(I)**2.0+0.002*CTIV(I)**3.0
  109 CTO(I)=29.036+45.73*CTOV(I)-0.136*CTOV(I)**2.0+0.002*CTOV(I)**3.0
C      DETERMINE WHICH FORMULA TO USE ACCORDING TO THE FUEL AND CALCULATE
C     * THE STOICHIOMETRIC FUEL AIR RATIO.
  110 GO TO(115,120),M
  115 FARS(I)=(97.02-65.02*F)/(1407.81-1201.89*F)
      GO TO 125
  120 FARS(I)=(114.0-82.0*F)/(1716.0-1510.0*F)
C      CALCULATE THE SPECIFIC GRAVITY OF THE METHANOL BLEND.
  125 SGB=RMF*SGM+SGG*(1-RMF)
C      DETERMINE THE PROPER AIR FLOW EQUATION AND CALCULATE THE AIR FLOW
C     *IN POUNDS PER HOUR.
  135 L=NS(I)
  140 GO TO(145,150,155,160,165,170),L
  145 AFLO(I)=(2.492012+32.85549*AFR(I)-16.78289*AFR(I)**2.0+5.349195*AF
     *R(I)**3.0-0.6569653*AFR(I)**4.0)*AFHCF*AFTCF*AFHCF
      GO TO 175
  150 AFLO(I)=(5.268344+79.83712*AFR(I)-44.28941*AFR(I)**2.0+14.58583*AF
     *R(I)**3.0-1.613422*AFR(I)**4.0)*AFHCF*AFTCF*AFPCF
      GO TO 175
  155 AFLO(I)=(24.86206+166.4272*AFR(I)-85.49280*AFR(I)**2.0+30.04943*AF
     *R(I)**3.0-4.0546*AFR(I)**4.0)*AFHCF*AFTCF*AFPCF
      GO TO 175
  160 AFLO(I)=(55.77166+396.2881*AFR(I)-217.2702*AFR(I)**2.0+75.48932*AF
     *R(I)**3.0-10.06206*AFR(I)**4.0)*AFHCF*AFTCF*AFPCF
      GO TO 175
  165 AFLO(I)=(178.0342+817.5067*AFR(I)-342.9848*AFR(I)**2.0+96.7033*AFR
     *(I)**3.0-13.90655*AFR(I)**4.0)*AFHCF*AFTCF*AFPCF
      GO TO 175
  170 AFLO(I)=(586.3607+1407.949*AFR(I)-485.0094*AFR(I)**2.0+65.9907*AFR
     *(I)**3.0)*AFHCF*AFTCF*AFPCF
C      CALCULATE THE FUEL FLOW IN POUNDS PER HOUR.
  175 IF(PM(I).LE.0)GO TO 179
      IF(PM(I).LE.20)GO TO 176
      IF(PM(I).LE. 30)GO TO 177
      IF(PM(I).LE.100)GO TO 178
      FF(I)=((SGG/SGB)**0.5)*(0.29*FFR(I)-0.4)
      GO TO 185
  176 FF(I)=(0.28414*FFR(I)-0.40857)
      GO TO 185
  177 FF(I)=(0.2850*FFR(I)-0.80)
      GO TO 185
  178 FF(I)=(0.27957*FFR(I)-0.30837)
      GO TO 185
  179 FF(I)=(0.28504*FFR(I)-0.22715)
C     CALCULATE THE BRAKE HORSE POWER.
  185 BHP=T(I)*RN(I)/5250.0
C     CALCULATE THE HP CORR FACTOR THEN THE CORR HP
  186 HPCF=(29.0/BP(I))*((DBT(I)+460.0)/545.0)**0.5
  187 CBHP(I)=BHP*HPCF
C     CALCULATE THE BRAKE SPECIFIC FUEL CONSUMPTION IN POUNDS PER BRAKE
C    *HORSE POWER HOUR.
  190 BSFC(I)=FF(I)/BHP
C     CALCULATE THE CORR BMEP IN PSI
  195 CBMEP(I)=CBHP(I)*792000.0/(D*RN(I))
C     CALCULATE THE VOLUMETRIC EFFECIENCY.
  200 VE(I)=(AFLO(I)*4535.6*(DBT(I)+460.0))/(BP(I)*RN(I)*D,
C     CALCULATE THE LOWER HEATING VALUE OF THE BLEND.
  205 RLHVB=RMF*RLHVM+(1.0-RMF)*RLHVG
C     CALCULATE THE BRAKE THERMAL EFFICIENCY.
  210 BTHE(I)=25+500.0/(BSFC(I)*RLHVB)
C     CALCULATE THE FUEL-AIR EQUIVALENCE RATIO.
  215 ER(I)=FF(I)/(AFLO(I)*FARS(I))
C     CALCULATE THE PERCENT CO2 IN THE EXHAUST.
  220 CO2P(I)=0.2*CO2R(I)
C     DETERMINE THE PROPER CO EQUATION AND CALCULATE THE PERCENT CO IN T
C    *HE EXHAUST.
      JN=J(I)
      GO TO(225,230,235,240),JN
  225 COP(I)=-0.00441o779+0.0048460079*COR(I)+0.00004076075*COR(I)**2.0+
     *0.0000002898798*COR(I)**3.0
      GO TO 245
  230 COP(I)=-0.0003475472+0.002411038*COR(I)+0.00000239808 9*COR(I)**2.0
     **0.000000340553 8*COR(I)**3.0
      GO TO 245
  235 COP(I)=-0.0262194+0.0509564 5*COR(I)-0.002153173*COR(I)**2.0+0.000
     *0923034A*COR(I)**3.0-0.00001220454*COR(I)**4.0+0.0000000005866721*
     *COR(I)**5.0
      GO TO 245
  240 COP(I)=-0.001714557+0.02073982*COR(I)+0.00006480206*COR(I)**2.0+0.
     *000000285859*COR(I)**3.0
C     DEFINE CHEMICAL ANALYSIS SUB. EQUATIONS
  245 CO2FD=CO2P(I)/100.0
      O2FD=O2P(I)/100.0
      COFD=COP(I)/100.0
      CH4OFD=CH3OHP(I)/100.0
      HCHOFD=HCHOP(I)/100.0
      CH4FW=HC(I)/1000000.0
      RNOXFW=RNOX(I)/1000000.0
      RRK=3.8
      XX1=((1.0-F)*(Y/2.0))+2.0*F
      XX2=((1.0-F)*X)+F
      BETA=1.0+(COFD/(CO2FD*RRK))
      GAMMA=(1.0+(2.0*CH4FW/BETA))**(-1.0)
      DELTA=XY1*GAMMA/BETA
      XX3=CO2FD+COFD+(CH4FW*GAMMA)
      XX4=CO2FD+(0.5*COFD)+O2FD-0.5
      XX5=0.5*(1.0+RNOXFW)
C     CALCULATE THE WET AND DRY EXHAST MOLES PER MOLE FUEL
  250 RND(I)=(XX2-(CH4FW*DELTA))/XX3
  251 RNW=(GAMMA*RND(I))+DELTA
C     CALCULATE THE RATIO OF WET TO DRY MOLES
  252 RATWD(I)=RNW/RND(I)
C     DEFINE MORE SUB. EQUATIONS
  260 RRN=(RND(I)*XX4)+(RNW*XX5)-(F/2.0)
      XX6=(1.0-F)*(12.0+X+Y)+(32.0*F)
C     CALCULATE THE CHEMICAL ANALYSIS F/A RATIO
  265 FAC=XX6/(RRN*157.28)
C     CALCULATE THE ANALYSIS EQUIVALENCE RATIO
  266 ERCHM(I)=FAC/FARS(I)
C     CALCULATE EMISSIONS ON A DRY BASIS
      CH4FD=CH4FW*RATWD(I)
      RNOXFD=RNOXFW*RATWD(I)
  270 CH4D(I)=CH4FD*1000000.0
  271 RNOXD(I)=RNOXFD*1000000.0
C     DEFINE MORE SUB. EQUATIONS
  272 XX7=(1.0-F)*X+F
      XX8=CO2FD+COFD+CH4FD+CH4OFD+HCHOFD
      XX9=(1.0-F)*((12.0*X)+Y)+(32.0*F)
      XX10=BSFC(I)*453.59
      XX11=(XX10*XX7)/(XX8*XX9)
C     CALCULATE THE MASS EMISSIONS
  275 HCM(I)=(12.0+B/A)*CH4FD*XX11
  276 COM(I)=28.0*COFD*XX11
  277 RNOXM(I)=(14.0+16.0*RK)*RNOXFD*XX11
  278 CO2M(I)=44.0*CO2FD*XX11
  279 O2M(I)=32.0*O2FD*XX11
      I=I+1
  280 IF(I.LE.10)GO TO 20
  285 WRITE(6,290)(NTEST(I),I=1,10),(PM(I),I=1,10),(SA(I),I=1,10),(RMV(I
     *),I=1,10),(T(I),I=1,10),(RN(I),I=1,10),(ER(I),I=1,10),(FAPS(I),I=1
     *,10),(BSFC(I),I=1,10),(CBHP(I),I=1,10)
  290 FORMAT(1H1, 9X,'TEST NO.   ',10I10//10X,'% METH.     ',10F10.2//10X,'
     *SPARK ADV.',10F10.1/12X,'DEG. BTDC '/10X,'MAN. VAC. ',10F10.2/12X,
     *'IN.CH.HG.'/10X,'TORQUE      ',10F10.2/12X,'FT. LBS.'/10X,'ENG. SPEED
     *',10F10.2/12X,'R.P.M.'/10X,'EQ. RATIO ',10F10.3/12X,'FUEL/AIR'/10X
     *,'F/A STOICH',10F10.4//10X,'B.S.F.C.   ',10F10.4/12X,'LBS/HP HR'/10
     *X,'COR B.H.P.',10F10.2)
  295 WRITE(6,300)(CBMEP(I),I=1,10),(VE(I),I=1,10),(BTHE(I),I=1,10),(O2P
     *(I),I=1,10),(COP(I),I=1,10),(CO2P(I),I=1,10),(CH3OHP(I),I=1,10),(H
     *CHOP(I),I=1,10),(RNO(I),I=1,10),(RNO2(I),I=1,10)
  300 FORMAT(/ 10X,'COR. BMEP.',10F10.2/12X,'P.S.I.'/10X,'VOL. EF. %',10
     *F10.2//10X,'B.TH.E. %',10F10.2//10X,'% O2        ',10F10.2//10X,'%
     *CO         ',10F10.4//10X,'% CO2      '10F10.2//10X,'% CH3OH    ',10F10
     *.2//10X,'% HCHO      ',10F10.2//10X,'NO. PPM W.',10F10.1//10X,'NO2
     *PPM W',10F10.1)
  305 WRITE(6,310)(RNOX(I),I=1,10),(HC(I),I=1,10),(O2M(I),I=1,10),(COM(I
     *),I=1,10),(CO2M(I),I=1,10),(RNOXM(I),I=1,10),(HCM(I),I=1,10),(ERCH
     *M(I),I=1,10),(NTEST(I),I=1,10)
  310 FORMAT(/ 10X,'NOX   PPM W',10F10.1//10X,'HC   PPM   W',10F10.1//10X,'
     *MASS O2    ',10F10.3/12X,'GRMS/HP HR'/10X,'MASS CO    ',10F10.3/12X,
     *'GRMS/HP HR'/10X,'MASS CO2   ',10F10.3/12X,'GRMS/HP HR'/10X,'MASS N
     *OX   ',10F10.3/12X,'GRMS/HP HR'/10X,'MASS HC    ',10F10.3/12X,'GRMS/
     *HP HR'/10X,'EQ.R.CHM. ',10F10.3/10X,'TEST NO.   ',10I10)
  312 WRITE(6,313)
  313 FORMAT(1H1,30X,'PAGE 2')
  315 WRITE(6,320)(NTEST(I),I=1,10),(DATE(I),I=1,10),(CH4D(I),I=1,10),(R
     *NOXD(I),I=1,10),(DBT(I),I=1,10),(WBT(I),I=1,10),(PP(I),I=1,10),(CT
     *I(I),I=1,10),(CTO(I),I=1,10)
  320 FORMAT(/10X,'TEST NO.   '10I10//10X,'DATE        ',10F10.2//10X,'HC P
     *PM D  ',10F10.1//10X,'NOx PPM D ',10F10.1//10X,'DRY B TEMP',10F10.
     *1/12X,'DEG.F.'/10X,'WET B TEMP',10F10.1/12X,'DEG.F.'/10X,'BAR.PRES
     *S.',10F10.2/12X,'INCH. HG.'/10X,'IN.COOL.T.',10F10.1/12X,'DEG.F.'/
     *10X,'OUT.COOL.T.',1F9.1,9F10.1/12X,'DEG.F.')
  325 WRITE(6,330),(EP(I),I=1,10),(AFLO(I),I=1,10),(FF(I),I=1,10),(ET1(I
     *),I=1,10),(ET2(I),I=1,10),(ET3(I),I=1,10),(ET4(I),I=1,10)
  330 FORMAT(/10X,'EXH.PRESS.',10F10.2/12X,'P.S.I.'/10X,'AIR FLOW  ',10F
     *10.2/12X,'LBS/HR'/10X,'FUEL FLOW ',10F10.2/12X,'LBS/HR'/10X,'EXH.
     *TEMP.'/10X,'CYL.NO. 1 ',10F10.1//10X,'CYL.NO. 2 ',10F10.1//10X,'CY
     *L.NO. 3 ',10F10.1//10X,'CYL.NO. 4 ',10F10.1)
  335 WRITE(6,340)(TIM1(I),I=1,10),(TIM3(I),I=1,10),(TIM4(I),I=1,10),(RN
     *D(I),I=1,10),(RATWD(I),I=1,10),(NTEST(I),I=1,10)
  340 FORMAT(//10X,'INT.MAN.T.'/10X,'CYL.NO.1,2',10F10.1//10X,'CYL.NO.3,
     *4',10F10.1//10X,'CARB. BASE',10F10.1//10X,'NO.D.MOLES',10F10.3/10X
     *'PER.MOLE F'/10X,'NO.M.W./D.',10F10.4//10X,'TEST. NO. ',10I10)
  345 GO TO 7
  999 STOP
      END
   @XQT
   @ADD M.SELECT2/TESTS
@BRKPT PRINT$
```

APPENDIX C

LIST OF STANDARD CONDITIONS

TEST RESULTS FIGURES

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TEST RESULTS FIGURES

FIGURE	TITLE	PAGE
C1	CO Emissions, %, Dry Exhaust at "Standard" Conditions Check Points Including Average Value ($\bar{x}$) and Standard Deviation (S).	187
C2	CO_2 Emissions, %, Dry Exhaust at "Standard" Conditions Check Points Including Average Value ($\bar{x}$) and Standard Deviation (S).	187
C3	NO_x and NO Emissions, ppm, Wet Exhaust at "Standard" Conditions Check Points Including Average Values ($\bar{x}$) and Standard Deviation (S).	188
C4	FID, HC Emissions, ppm, Wet Exhaust at "Standard" Conditions Check Points Including Average Value ($\bar{x}$) and Standard Deviation (S).	188
C5	Wet and Dry Bulb Temperature at "Standard" Conditions Check Points Including Average Values ($\bar{x}$) and Standard Deviations (S).	189
C6	Barometric Pressure at "Standard" Conditions Check Points Including Average Value ($\bar{x}$) and Standard Deviation (S).	189
C7	Inlet and Exit Coolant Temperature at "Standard" Conditions Check Points Including Average Values ($\bar{x}$) and Standard Deviations (S).	190
C8	Air Mass Flow Rate at "Standard" Conditions Check Points Including Average Value ($\bar{x}$) and Standard Deviations (S).	190
C9	Fuel Mass Flow Rate at "Standard" Conditions Check Points Including Average Value ($\bar{x}$) and Standard Deviation (S).	191
C10	Exhaust Temperatures at "Standard" Conditions Check Points Including Average Values ($\bar{x}$) and Standard Deviations (S).	191
C11	Intake Manifold Temperatures at "Standard" Conditions Check Points Including Average Values ($\bar{x}$) and Standard Deviations (S).	192

TEST RESULTS FIGURES - Cont.

FIGURE	TITLE	PAGE
C12	Volumetric Efficiency at "Standard" Conditions Check Points Including Average Value ($\bar{x}$) and Standard Deviation (S).	192
C13	Brake Thermal Efficiency at "Standard" Conditions Check Points Including Average Value ($\bar{x}$) and Standard Deviation (S).	193
C14	O_2 Mass Emissions at "Standard" Conditions Check Points Including Average Value ($\bar{x}$) and Standard Deviation (S).	193
C15	CO Mass Emissions at "Standard" Conditions Check Points Including Average Value ($\bar{x}$) and Standard Deviation (S).	194
C16	CO_2 Mass Emissions at "Standard" Conditions Check Points Including Average Value ($\bar{x}$) and Standard Deviation (S).	194
C17	NO_x Mass Emissions at "Standard" Conditions Check Points Including Average Value ($\bar{x}$) and Standard Deviation (S).	195
C18	FID HC Mass Emissions at "Standard" Check Points Including Average Value ($\bar{x}$) and Standard Deviation (S).	195
C19	Chemical Fuel-Air Equivalence Ratio, Φ_c at "Standard" Conditions Check Points Including Average Value ($\bar{x}$) and Standard Deviation (S).	196

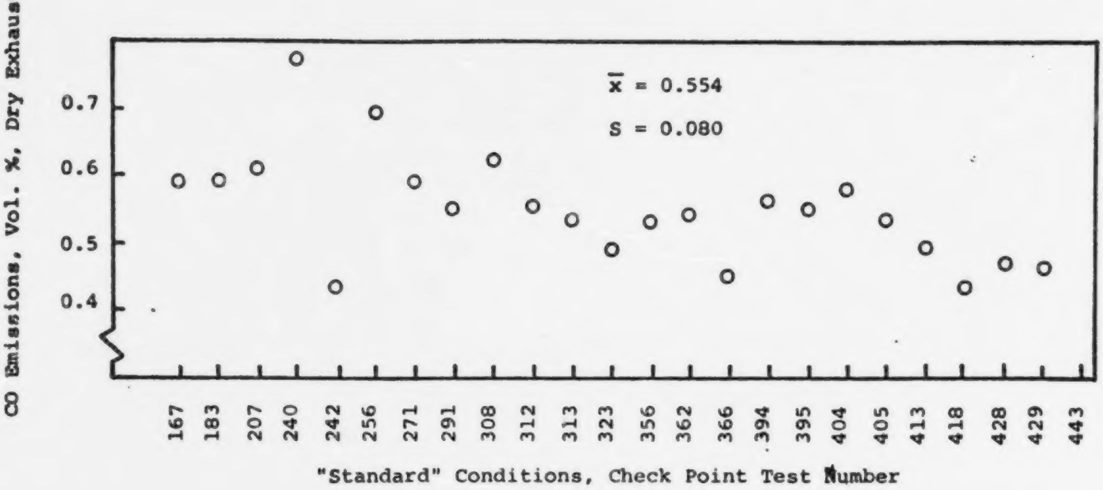

Figure C1 - CO Emissions, %, Dry Exhaust at "Standard" Conditions Check Points Including Average Value (x̄) and Standard Deviation (S).

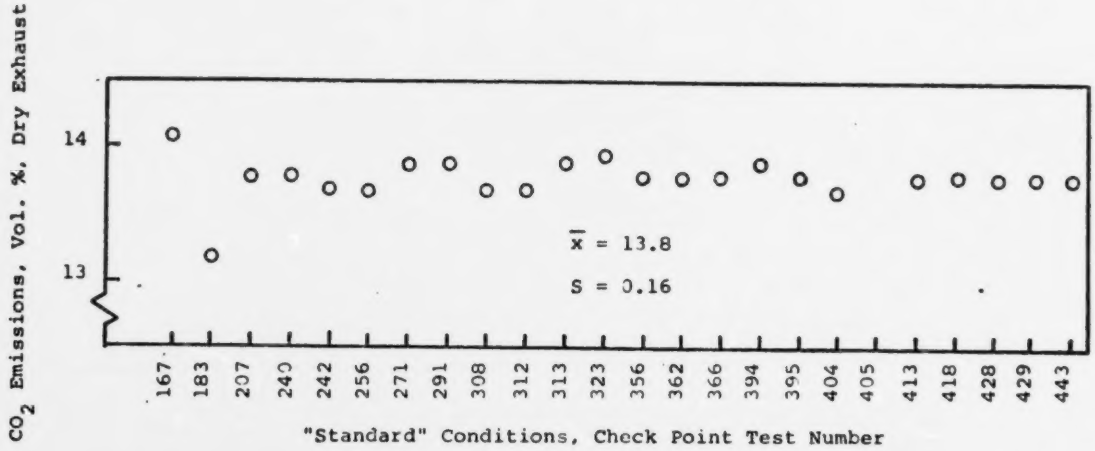

Figure C2 - CO_2 Emissions, %, Dry Exhaust at "Standard" Conditions Check Points Including Average Value (x̄) and Standard Deviation (S).

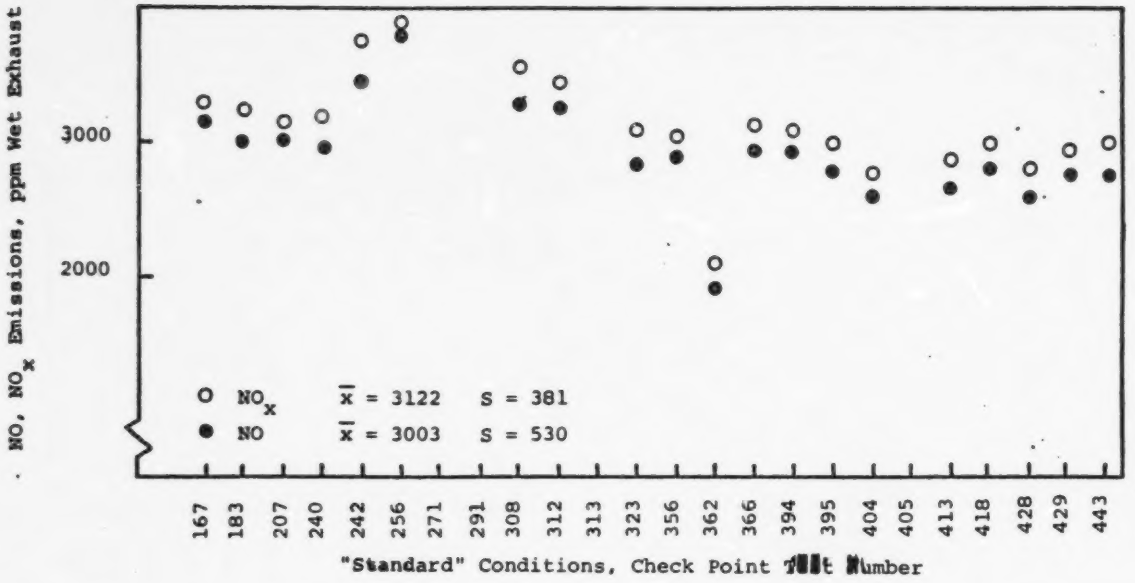

Figure C3 - NO_x and NO Emissions, ppm, Wet Exhaust at "Standard" Conditions Check Points Including Average Values ($\overline{x}$) and Standard Deviations (S).

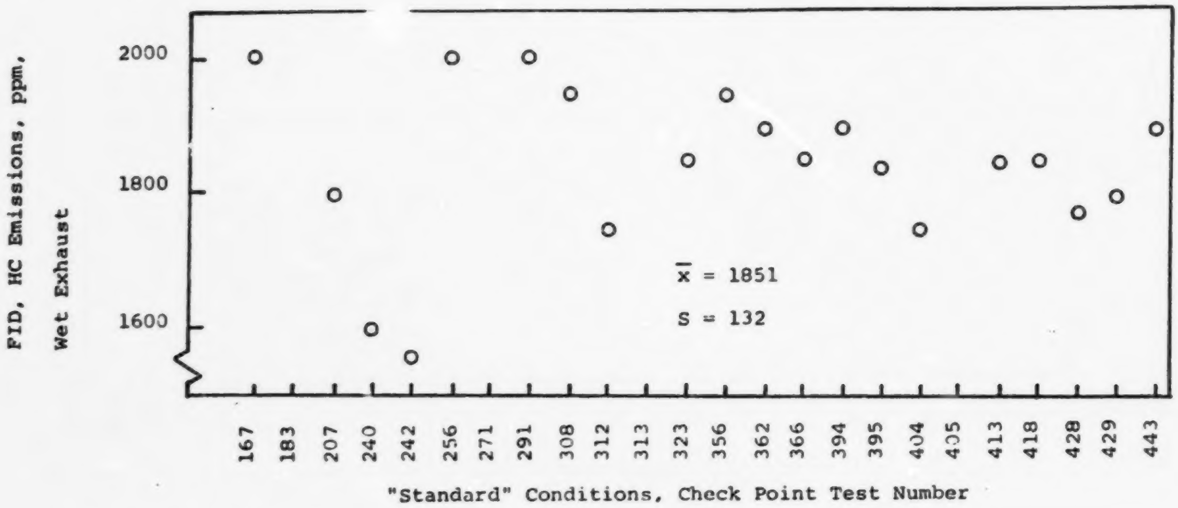

Figure C4 - FID, HC Emissions, ppm, Wet Exhaust at "Standard" Conditions Check Points Including Average Value ($\overline{x}$) and Standard Deviation (S).

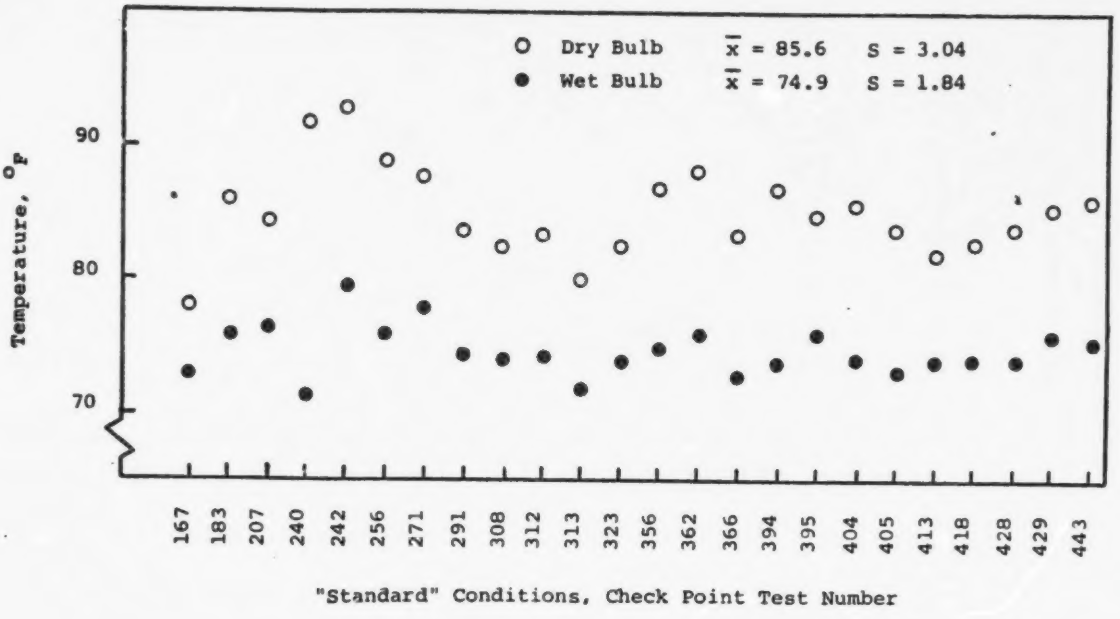

Figure C5 - Wet and Dry Bulb Temperature at "Standard" Conditions Check Points Including Average Values ($\overline{x}$) and Standard Deviations (S).

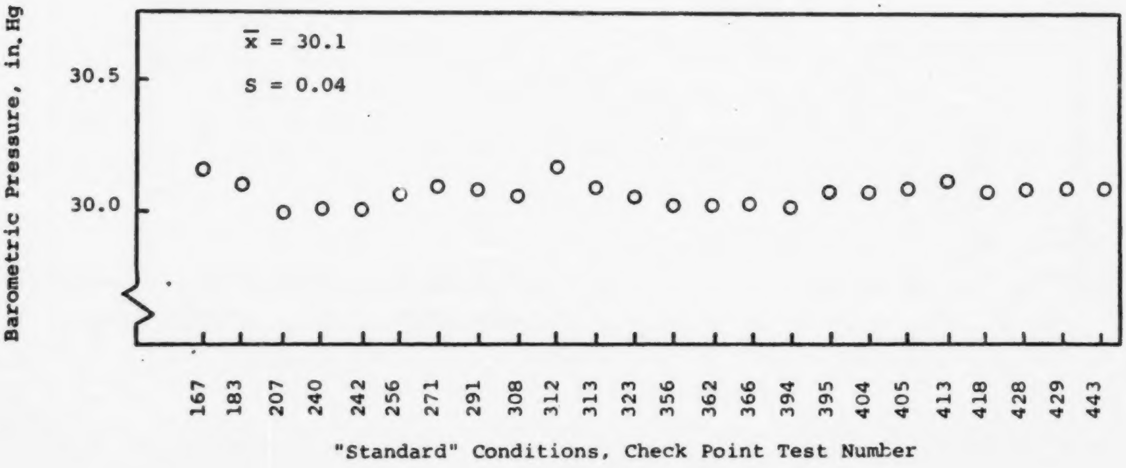

Figure C6 - Barometric Pressure at "Standard" Conditions Check Points Including Average Value ($\overline{x}$) and Standard Deviation (S).

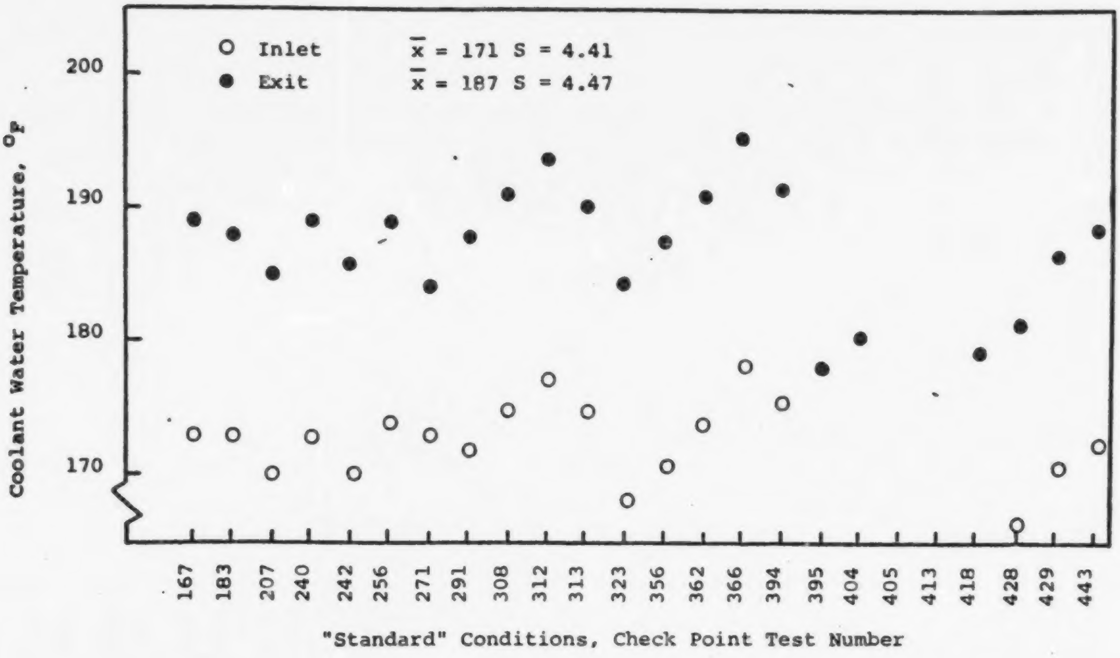

Figure C7 - Inlet and Exit Coolant Temperature at "Standard" Conditions Check Points Including Average Values (x̄) and Standard Deviations (S).

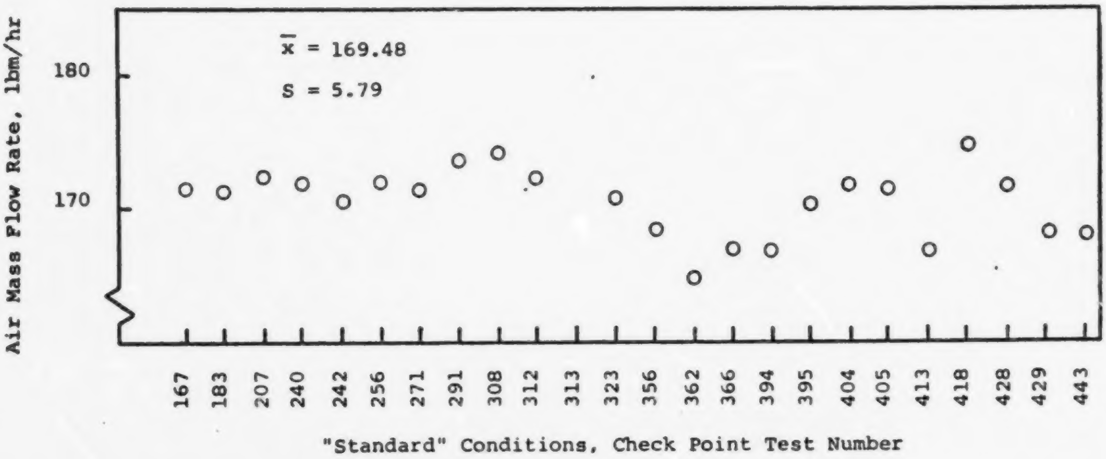

Figure C8 - Air Mass Flow Rate at "Standard" Conditions Check Points Including Average Value (x̄) and Standard Deviation (S).

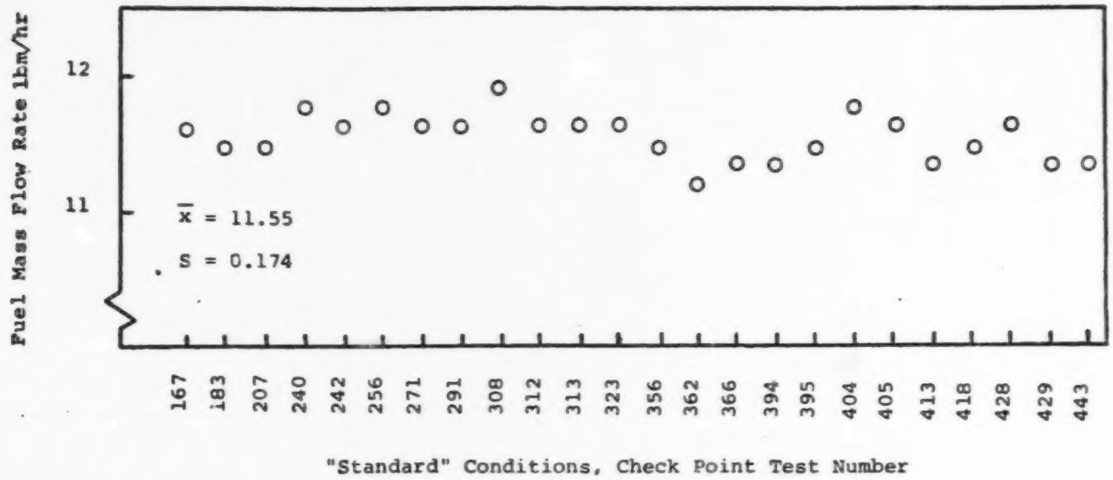

Figure C9 - Fuel Mass Flow Rate at "Standard" Conditions Check Points Including Average Value $(\bar{x})$ and Standard Deviation (S).

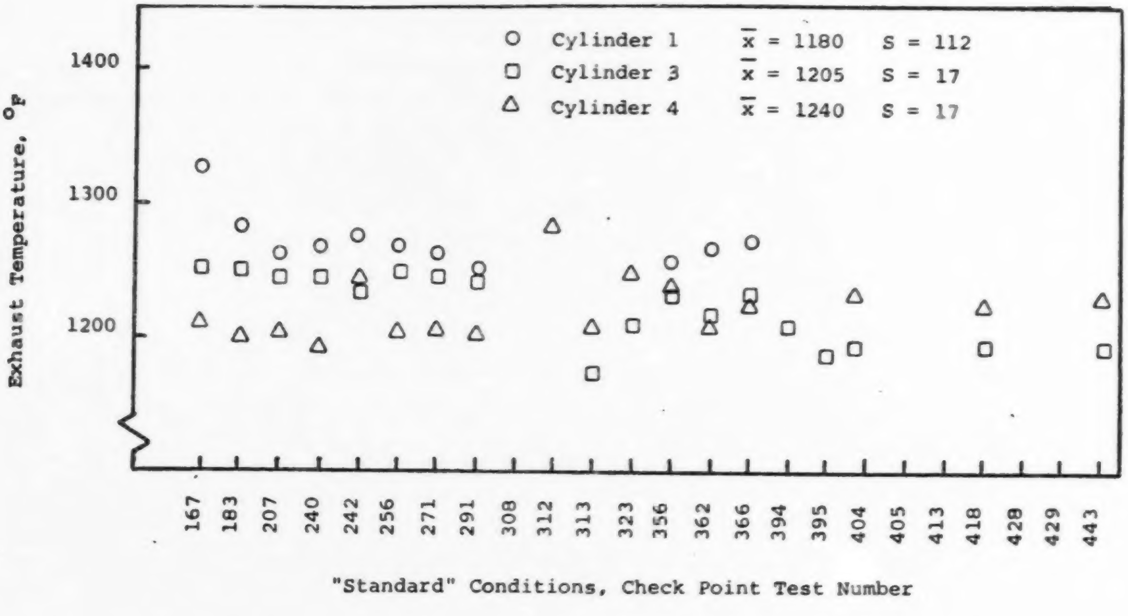

Figure C10 - Exhaust Temperatures at "Standard" Conditions Check Points Including Average Values $(\bar{x})$ and Standard Deviations (S).

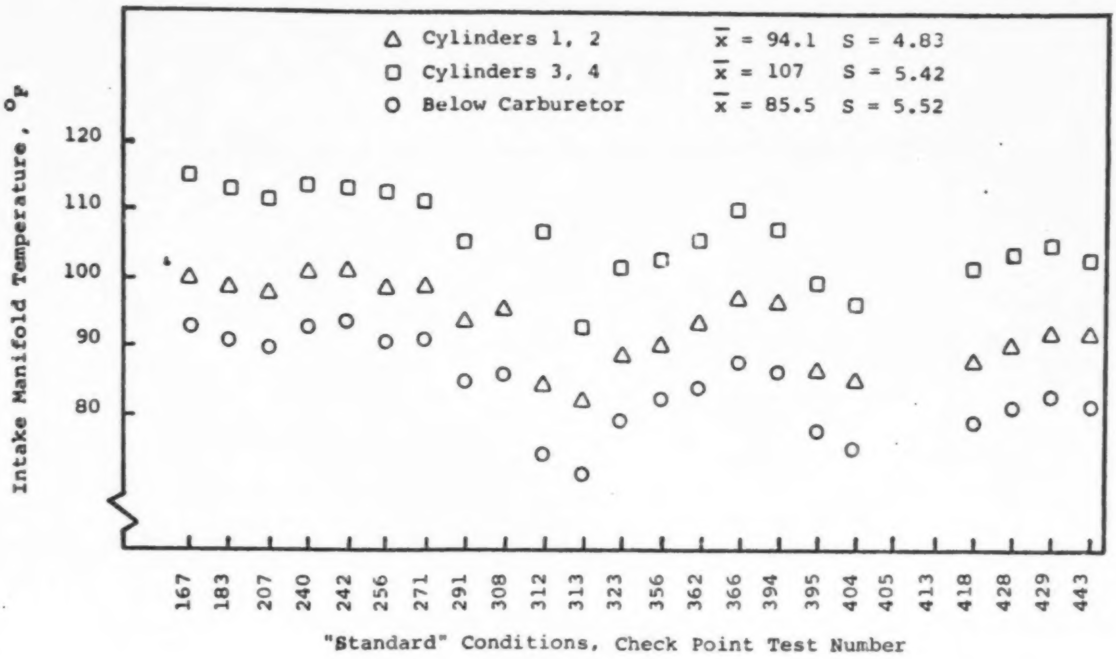

Figure C11 - Intake Manifold Temperatures at "Standard" Conditions Check Points Including Average Values ($\bar{x}$) and Standard Deviations (S).

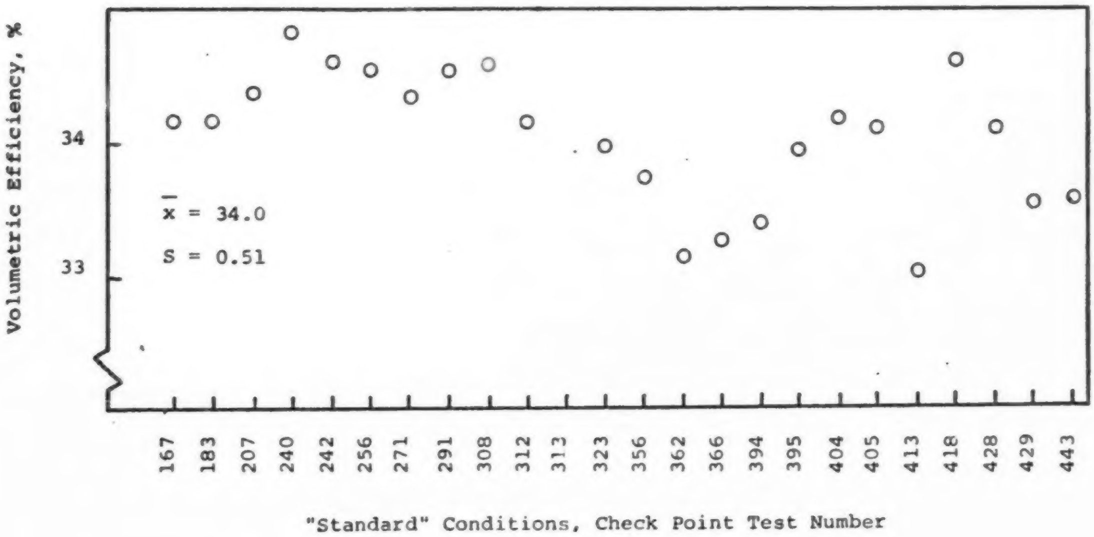

Figure C12 - Volumetric Efficiency at "Standard" Conditions Check Points Including Average Value ($\bar{x}$) and Standard Deviation (S).

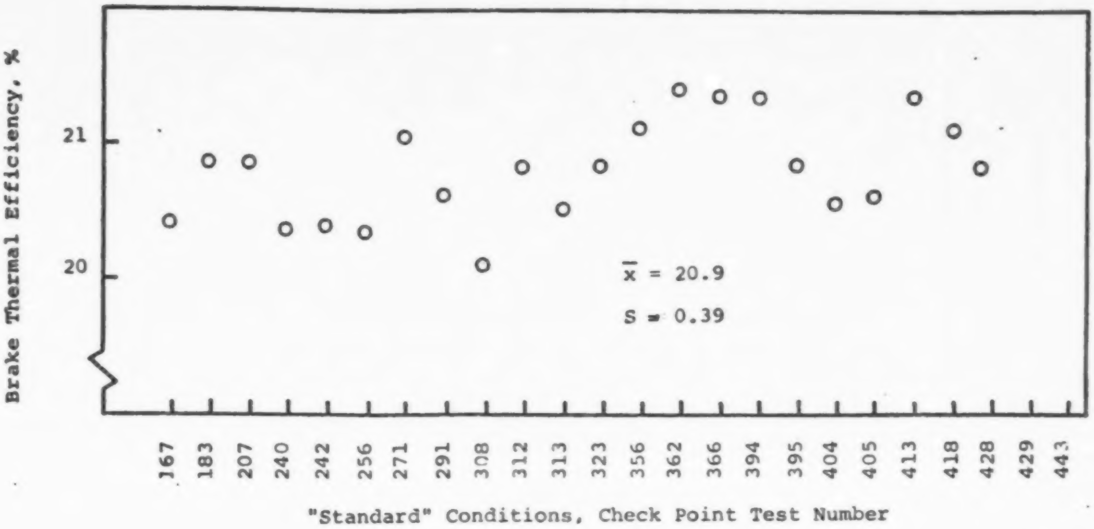

Figure C13 - Brake Thermal Efficiency at "Standard" Conditions Check Points Including Average Value ($\bar{x}$) and Standard Deviation (S).

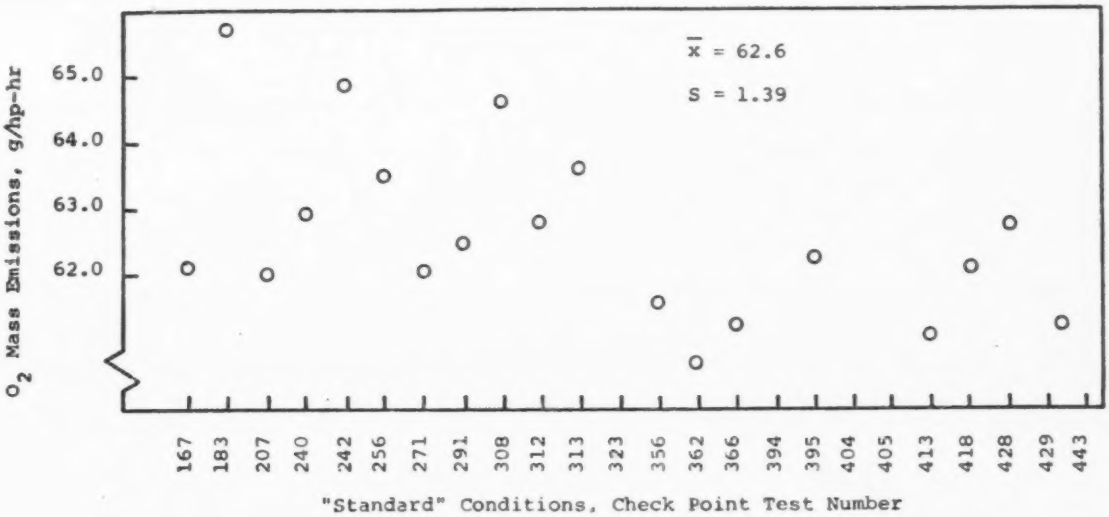

Figure C14 - O_2 Mass Emissions at "Standard" Conditions Check Points Including Average Value ($\bar{x}$) and Standard Deviation (S).

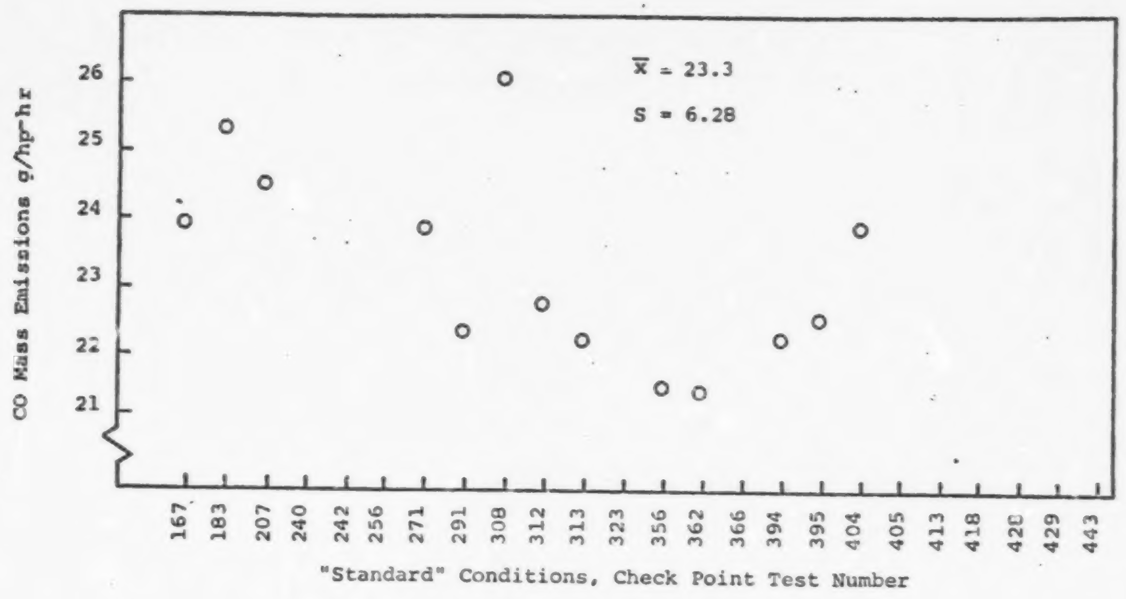

Figure C15 - CO Mass Emissions at "Standard" Conditions Check Points Including Average Value ($\overline{x}$) and Standard Deviation (S).

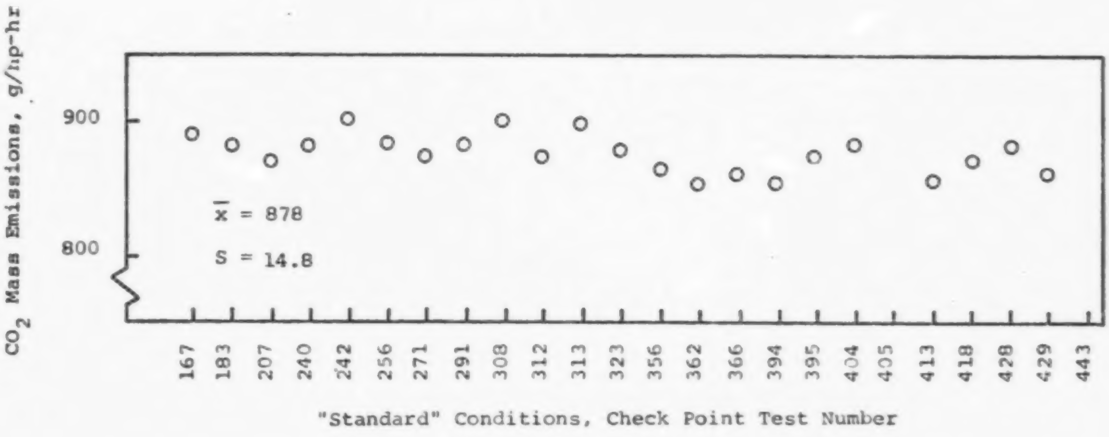

Figure C16 - CO_2 Mass Emissions at "Standard" Conditions Check Points Including Average Value ($\overline{x}$) and Standard Deviation (S).

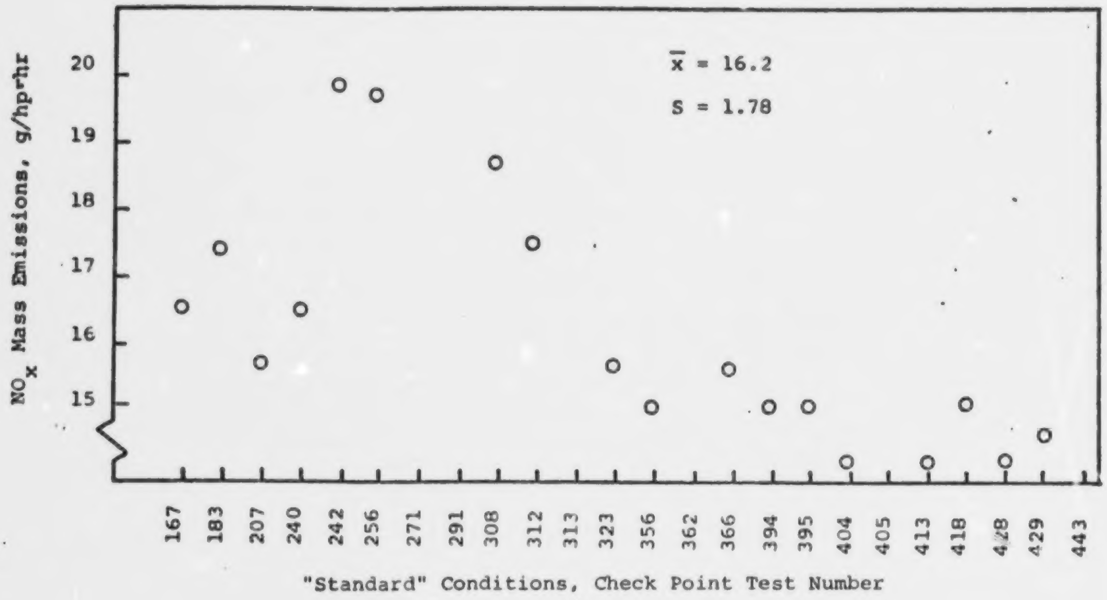

Figure C17 - NO_x Mass Emissions at "Standard" Conditions Check Points Including Average Value ($\bar{x}$) and Standard Deviation (S).

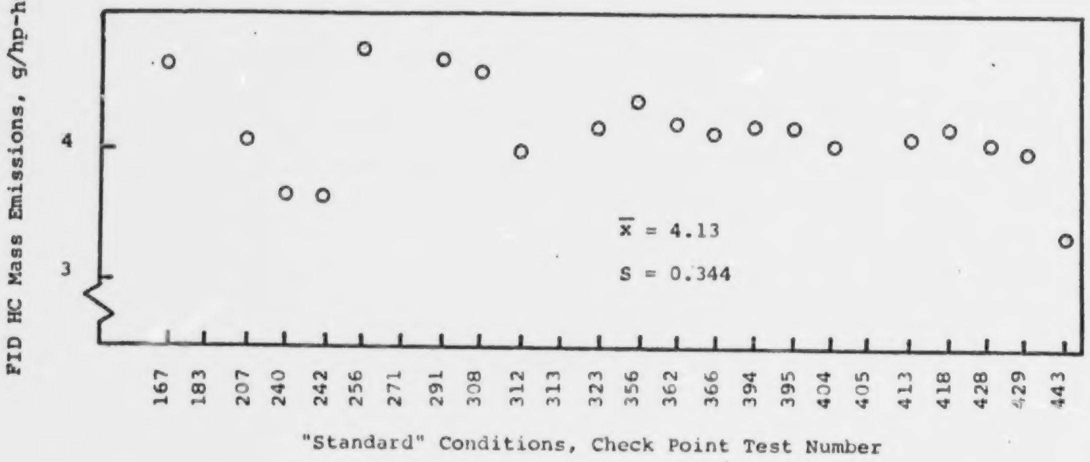

Figure C18 - FID HC Mass Emissions at "Standard" Conditions Check Points Including Average Value ($\bar{x}$) and Standard Deviation (S).

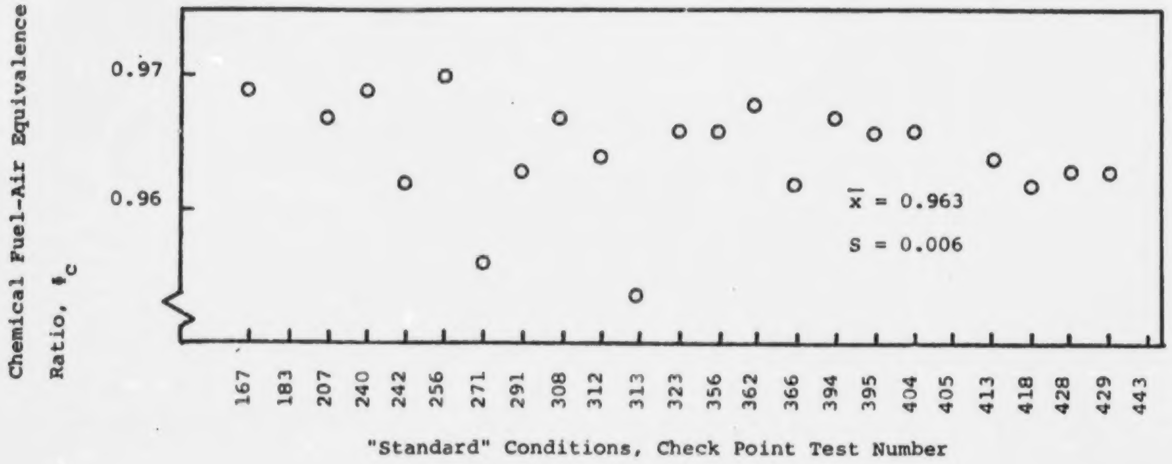

Figure C19 - Chemical Fuel-Air Equivalence Ratio, ϕ_c at "Standard" Conditions Check Points Including Average Value ($\overline{x}$) and Standard Deviation (S).